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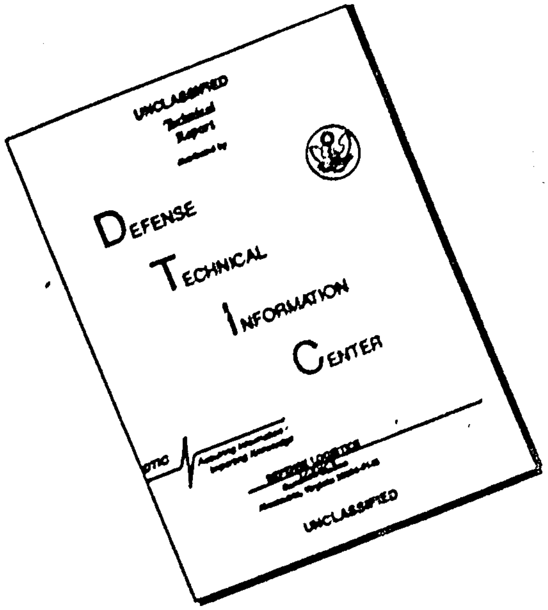

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NELL AIRCRAFT CORPORATION

BERT-ST. LOUIS MUNICIPAL AIRPORT

DETAILED FINAL REPORT OF RESEARCH ON
HIGH-SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME VII

SAMPLE AIRCRAFT POWER PLANT AND DUCT ANALYSIS

OFFICE OF NAVAL RESEARCH, AMPHIBIOUS BRANCH
PROJECT NR 250-001 CONTRACT N[illegible]

Report 1905-[illegible] Serial 15
[illegible] December 1950

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Enclosure (5) to
MAC Letter 2136-70F-1756

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REPORT 1905-A

DATE 20 December 1950

REVISED

McDONNELL Aircraft Corporation

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DETAILED FINAL REPORT OF RESEARCH ON HIGH SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME VII

SAMPLE AIRCRAFT POWER PLANT AND DUCT ANALYSIS

SUBMITTED UNDER Contract N9onr-94901 to the Office of Naval Research, Amphibious Branch, Project NR [illegible]-001

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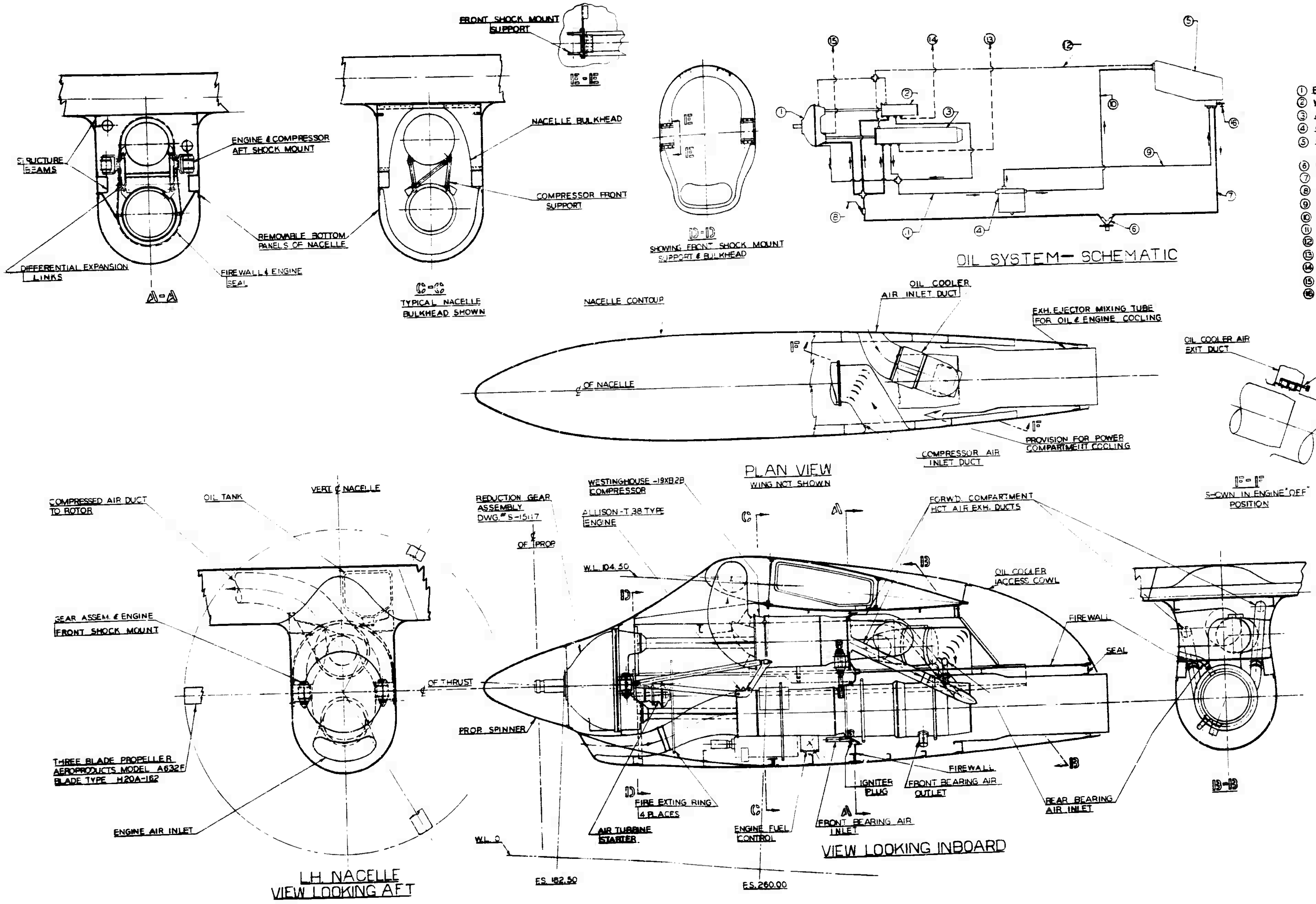

LEGEND

1. REDUCTION GEAR ASSEMBLY
2. WESTING'SE. 19XB2B COMPRESSOR
3. ALLISON-T38 TYPE ENGINE
4. OIL COOLER
5. OIL TANK — TOTAL CAP.- 17.5 GAL. OIL CAP. - 14.5 GAL.
6. DRAIN VALVE
7. OIL SUPPLY
8. OIL 'IN' TEMP
9. OIL COOLER BYPASS
10. RETURN- OIL COOLER TO TANK
11. HOT OIL RETURN TO COOLER
12. OIL TANK VENT
13. ENGINE OIL PRESS.
14. COMPRESSOR OIL PRESS.
15. REDUCTION GEAR OIL PRESS.
16. SUMP DRAIN VALVE

NOTES:-
1. FOR CONTINUATION OF COMPRESSED AIR DUCT SEE INBOARD PROFILE DWG.# S-1 B5 ROTOR HUB ASSEMBLY DWG.# S-2538

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POWER PLANT INSTALLATION
S-15118

1. GENERAL POWER PLANT DESCRIPTION

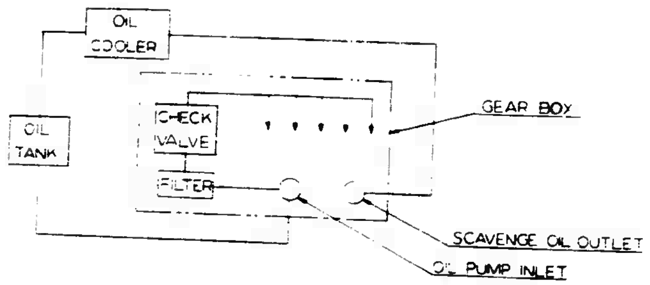
1.1 General - The MAC Model 78 is provided with two gas turbine engines which drive either compressors for furnishing air to the pressure jet driven rotor or tractor propellers for high speed forward flight. A power unit nacelle is mounted on either side of the fuselage.

1.2 Engine - An Allison Model 501 gas turbine power section is mounted in each nacelle supplying shaft power to the propeller and compressor. A cooling air ejector is fitted to the engine exhaust pipe, drawing cooling air over the engine compressor section, combustion section, and oil radiator.

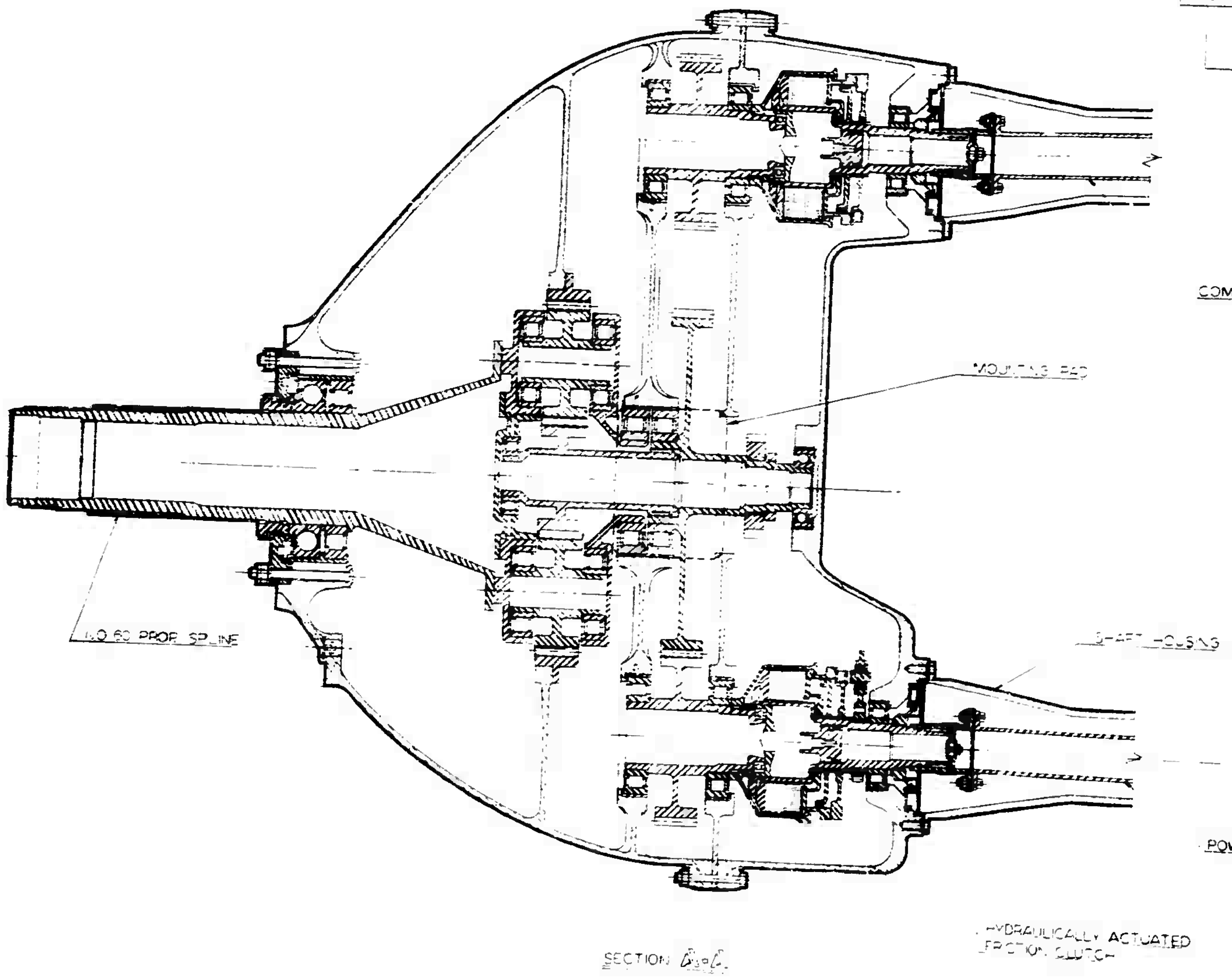
1.3 Pressure Jet Compressor - A Westinghouse 19XB axial flow compressor is employed to supply compressed air through a duct system to the rotor tip burners. This compressor is mounted directly above the engine with the compressor operated at engine speed by means of a drive shaft connected to the turbine shaft flange at the final discharge stage of the compressor.

1.4 Propeller - An Aeroproducts Model A632F propeller is mounted in the nose of each nacelle. During normal propeller operation, the propeller pitch is controlled by the engine control system. When the compressor is engaged to the engine, the propeller is held at the pitch resulting in minimum power absorption.

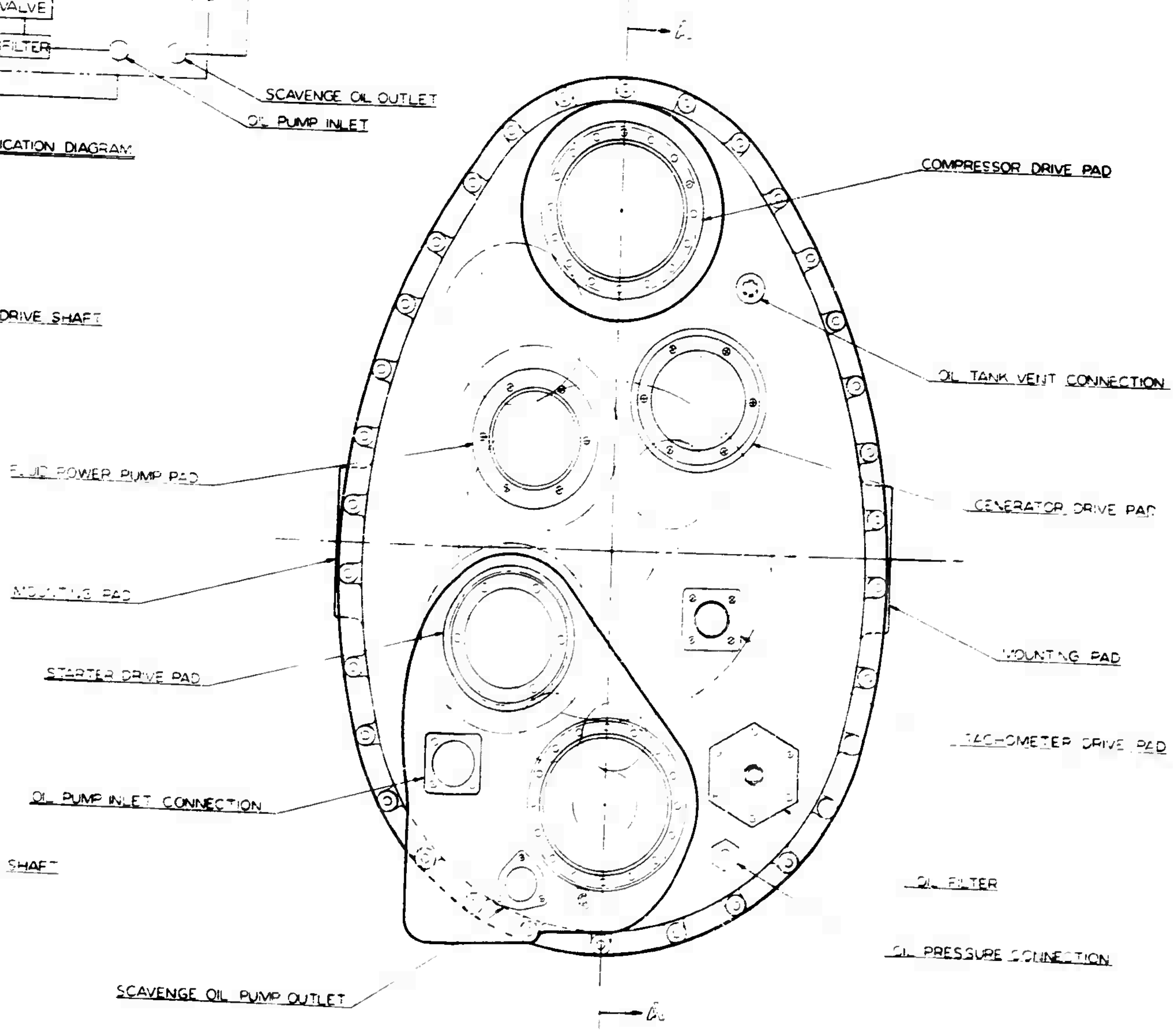
1.5 Gear Box - The engine drives the propeller and axial flow compressor by means of a modified Allison XT-38 gear box. The compressor shaft rotates in the opposite direction from the engine drive shaft at the same speed as the engine. Also included in the gear box section is one clutch permitting the engine to be disengaged from the gear box, and a second



LUBRICATION DIAGRAM



SECTION C-C



NOTES:

1. FIRST STAGE SPUR GEAR REDUCTION RATIO SAME AS THAT OF XT-38. PLANETARY GEARING PROP SHAFT & BEARINGS IDENTICAL WITH XT-38 GEAR BOX.
2. OVERALL REDUCTION 1:7.95
3. ENGINE RPM 14,300 PROP SHAFT RPM 1600

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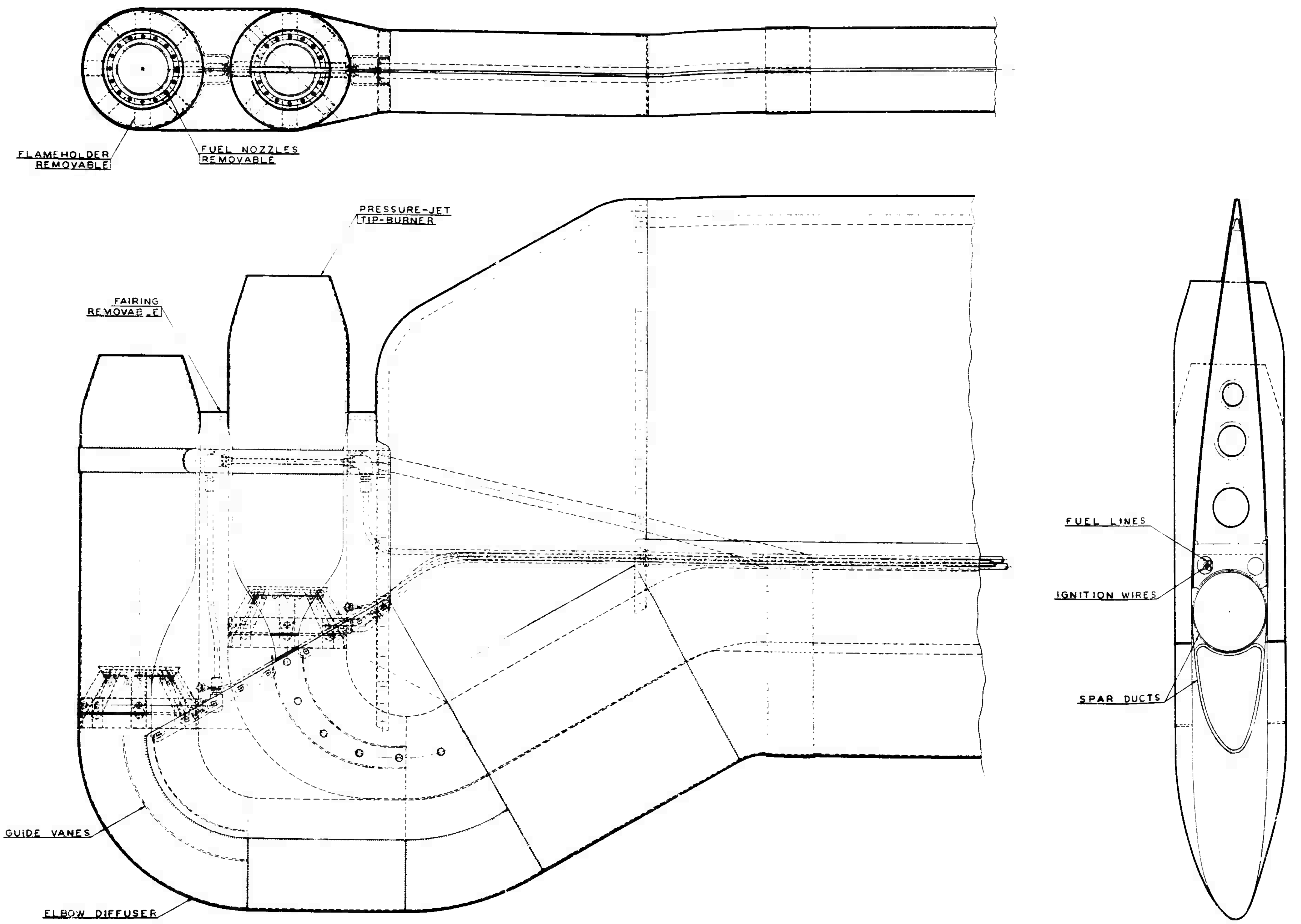
TRANSMISSION ASSEMBLY
S-15117

clutch which disengages the compressor. The rear face of the gear box provides the necessary accessory mounting pads and gear drives for the engine starter, generator, hydraulic pump, tachometer, and the connections for the gear box oil system and the propeller brake and governor controls. The starter gear train is connected to the engine drive shaft on the engine side of the clutch permitting the engine to be started while disengaged from the gear box.

1.6 Engine Starter - A single Airesearch air bleed gas turbine compressor is employed to drive a pneumatic starter mounted on each of the two engine gear boxes.

1.7 Rotor Tip Pressure Jets - Two burners are mounted at the tip of each of the three rotor blades. Compressed air supplied from the compressor is delivered to the tip burners through a duct system. Fuel is injected into the tip burners where combustion occurs, initiated by spark ignition.

1.8 Fuel System - The Model 78 fuel system is shown schematically in figure 1. This system was designed in accordance with specification SR-73D. Fuel cells totalling 627 gallons may be filled in a conventional method through the filler necks provided in each wing or by a single point pressure fueling fitting located on the left side of the fuselage. Defueling is made possible through the pressure fueling system by opening a shut-off valve located in the fuselage. This valve is normally closed to prevent inter-cell fuel flow through the pressure fueling system, while check valves prevent outboard fuel flow from the fuselage tank.



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ROTOR TIP BURNERS
S-12543

Fuel is delivered to the engine fuel control by two submerged boost pumps located in the sump of the fuselage fuel cell. The fuel to each power section enters through a common selector valve. Tip burner fuel flow is controlled by a rotor driven governor-pump unit. Fuel inlet pressure for this unit is provided by the engine boost pump. When the tip burners are inoperative, fuel to the rotor system is shut off by a valve integral to the rotor governor. For single engine operation, a solenoid valve, located in the rotor hub shuts off the fuel to half of the tip burners.

2. [illegible]

[illegible]

[illegible] ... required.

During [illegible] ... [illegible]

[illegible] ... recovering [illegible]

b. [illegible] — [illegible]

[illegible] ... operating [illegible] ... In order [illegible] allow [illegible] second [illegible] started [illegible] allow the second [illegible] compressor [illegible] ... equal [illegible] ... stopped the difference [illegible] cause the [illegible] compressor. [illegible] atmosphere [illegible] is blocked from the delivery system. In addition, [illegible] at such a great [illegible] compressor

operating at the lower speed.

In order to obtain optimum pressure jet performance during single engine operation when the air flow is only one half of the normal flow, it is necessary to reduce the tip burner total exhaust nozzle area by 50 per cent. This is accomplished by closing the butterfly valves located in the aft duct in the root of each rotor blade, thus removing the three inner tip burners from the system. Actuation of this butterfly valve is automatically controlled as explained in section 2.3.

2.3 Pressure Jet Fuel Control - Fuel flow to the rotor tip burners is controlled by a rotor speed governor which meters fuel as necessary to maintain a constant selected rotor speed during all jet powered rotor operation. Thus as the rotor load changes, the pressure jet fuel flow is automatically adjusted to hold rotor speed, completely relieving the pilot of this duty. This type of rotor speed and tip jet fuel control has been performing satisfactorily in flight for a period of three years on the McDonnell XH-20 ram jet powered helicopter.

During periods of single engine operation, the flapper door of the air control valve (see section 2.2) actuates switches which closes a fuel shut-off solenoid valve located in the rotor hub. This solenoid valve shuts off the fuel flow to the three inner tip burners. Also connected to the manifold supplying fuel to the inner set of tip burners are actuating cylinders controlling the butterfly valves located in each rotor blade in the ducts supplying compressed air to the inner set of tip burners (see section 2.2). These cylinders are arranged so as to hold the butterfly valves open when fuel pressure exists in the manifold supplying fuel

to the inner set of tip burners, and allows the butterfly valves to close when the solenoid valve shuts off the fuel in this manifold.

SYMBOLS

A	area	ft^2 unless otherwise noted
a	speed of sound	ft/sec
c_p	specific heat at constant pressure	BTU/#°R
D	hydraulic diameter	ft
F	thrust	#
F_o	compressibility factor $1 + \frac{M^2}{4} + \frac{M^4}{40} + \frac{M^6}{1600} + \ldots\ldots$	
f	wall friction factor	
f/a	fuel-air ratio	
g	acceleration of gravity 32.2 ft/sec²	
H	total head	$\#/ft^2$
HP	horsepower	
H_2/H_o	total pressure recovery	
h_v	lower heating value 18,000 BTU/# for gasoline	
J	mechanical equivalent of heat 778 ft#/BTU	
l	length	ft
M	Mach number	
m	mass rate of flow	slugs/sec
P	absolute static pressure	$\#/ft^2$ unless otherwise noted
P_T	absolute total pressure	$\#/ft^2$ unless otherwise noted
Q	volume rate of flow	$\#/ft^2$ unless otherwise noted
q	dynamic pressure	$\#/ft^2$ unless otherwise noted
q_o	impact pressure qF_o	$\#/ft^2$ unless otherwise noted
R	gas constant	ft#/#°R

RN	Reynolds number	
S HP	shaft horsepower	
T	static temperature	°R
T_T	total temperature	°R
V	velocity	ft/sec
V_T	tangential velocity	ft/sec
v	specific volume	$ft^3/\#$
W	weight rate of flow	#/sec
α	angle of attack	degrees
γ	ratio of specific heats	
Δ	used to represent a change in another quantity	
δ	$P_{T_2}/14.7$ when P_{T_2} is expressed in PSIA	
θ	$T_{T_2}/518.4$	
η	efficiency	
ρ	mass density	$slugs/ft^3$
ω	rotational velocity	radians/sec

Subscripts

0	free stream	i	inlet
1, 2, etc.	station numbers	j	jet
a	air	ot	total loss
b	burning	p	primary
c	compressor	s	secondary
f	fuel	TR	temperature rise
g	gas - products of combustion		

3. ANALYSIS OF POWER PLANT DUCTS

3.1 General - The analysis of the Model 78 duct system is presented in accordance with the U. S. Navy Aeronautical Specification NAVAER SR-160, "Specification for the Calculation of Duct losses, Turbo-Jet and Gas Turbine Engines".

This section includes the analysis of the inlet ducts supplying air to the two Allison Model 501 power sections, the inlet ducts supplying air to the two Westinghouse 19XB compressors, and the engine exhaust system including the cooling ejector.

3.2 Description of Ducts - The engine inlet duct is approximately five feet long with a well-rounded lip. The duct increases in cross-sectional area from 160 square inches at the inlet to 186 square inches at the engine face. The annular flow area at the engine compressor face is 160 square inches.

The 19XB compressor inlet duct is about three feet long and has a well-rounded lip. The duct increases in cross-sectional area from 140 square inches to 160 square inches at a station near the compressor face. The annular area at the compressor face is 138 square inches.

The engine exhaust tailpipe is shrouded with an ejector which is split by radial dividers into three parts drawing cooling air through the forward engine compressor compartment, the engine combustion chamber compartment, and the oil cooler.

Figure 3 presents a schematic of the ducting arrangement and cross-sectional areas.

3.3 Results of Analysis - The total pressure recovery for the engine and the compressor inlets is shown in figure 4. It is based on a series of wind tunnel and flight tests [illegible] by MAC on comparable installations (references 1 and 2).

Tests of similar installations [illegible] indicate that the engine and compressor inlet ducts should have a total pressure recovery of 92% under sea level static conditions without benefit of propeller ram.

Tables 1 and [illegible] present the detailed analysis of [illegible] re- covery [illegible] the engine and compressor. [illegible] 3, [illegible] area, equivalent [illegible] conical angle of diffusion, [illegible], and [illegible] velocity [illegible] axial [illegible] through 8 for the engine and compressor [illegible].

[illegible] (figures [illegible] and 10) [illegible] 8 [illegible] a MAC [illegible] tunnel [illegible].

Data presented in reference [illegible] shows that a secondary air flow of [illegible].3 lb/sec may be induced by an engine airflow of [illegible] lb/sec (static sea level, normal power). This ejector is considered satisfactory for the power plant cooling requirements. Tests of a MAC designed [illegible] ejector [illegible] low cooling losses may be expected from this design. Cross section area, equivalent conical angle of diffusion and exhaust Mach number [illegible] axial [illegible] for the exhaust ducts are presented in figures 11 and 12.

The analysis of the [illegible] compressed air duct system from the compressor [illegible], [illegible], is included in the pressure jet [illegible].

4. ALLISON MODEL 501 POWER SECTION PERFORMANCE

4.1 Engine Performance - The Allison Model 501 gas turbine engine performance was evaluated by the method presented in the engine specification (reference 5). Reference 5 represents the most recent Navy approved specification for the power section performance. Inlet duct total pressure recovery was based upon the duct analysis presented in section 3. Values of H_2/H_0 from figure 4 were used for the engine performance calculations.

During powered-rotor flight with the propeller in the pitch resulting in minimum power absorption it is assumed that the propeller absorbs 6% of the available engine shaft horsepower. Accordingly the power available to drive the compressor, as presented in figure 13 has been reduced by 6%.

As noted in section 2.1 the engine will be operated at constant normal speed (14,000 rpm) during all periods that it is engaged to the compressor. This necessitates, under certain conditions, that the turbine inlet temperature exceed the normal rated temperature, but under no conditions will it exceed the allowable military temperature. In view of the allowable operating time of 30 minutes at military power this type of operation is considered satisfactory especially as it is accomplished at a reduced engine speed. Figure 13 presents a plot of horsepower available and horsepower required versus altitude for the most critical conditions at 14,000 rpm and a turbine-in temperature of 1935°R.

Figures 14 through 22 present shaft horsepower, net jet thrust, and fuel flow for propeller operation of each engine in the anticipated operating ranges of flight velocity and altitude. Performance was determined in accordance with the engine specification (reference 5) using the estimated inlet total pressure recovery presented in figure 4.

[illegible] JET [illegible] PERFORMANCE

.1 [illegible] Performance - [illegible] data [illegible] noted in the text [illegible]. In [illegible] performance [illegible] it was necessary [illegible] horse-power required versus pressure ratio curve based [illegible] ic tempera-ture rise efficiency data [illegible] in reference [illegible]. [illegible] quation:

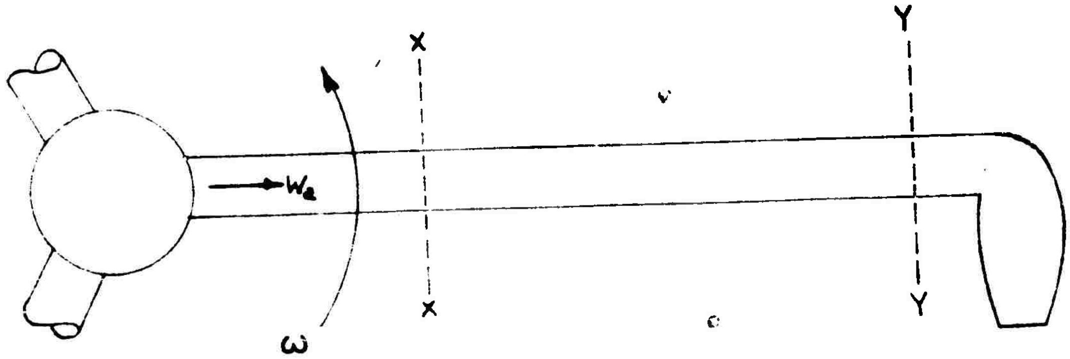
$$HP = \frac{1}{\eta_{TR}} \frac{RT}{550} \left(\gamma/_{\gamma-1}\right)\left[\left(P_{T_3}/P_{T_2}\right)^{\gamma-1/\gamma} - 1\right] W_a \qquad 1$$

was employed for this [illegible]. The resulting curve ([illegible]) was checked by [illegible] and [illegible] acceptable [illegible] the [illegible] re jet performance [illegible]. Figures [illegible] are as presented in reference 5.

.2 Tip Burner Performance - [illegible] figure 2[illegible].

.[illegible]1 [illegible] - [illegible] air flows [illegible]

Considering a rotor blade as shown below with air flowing through the blade passage and being burned in the tip burner, the power required to



accelerate the air from the tangential velocity at station X to the tangential velocity at station Y is:

$$\text{POWER} = \frac{W_a\left(V_{T_Y}^2 - V_{T_X}^2\right)}{2g} \qquad 2$$

also, the power required for isentropic compression of the air from station X to station Y is: (reference 7).

$$\text{POWER} = J\,c_p T_{T_X}\left[\left(\frac{P_{T_Y}}{P_{T_X}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] W_a \qquad 3$$

Equating equation 2 and equation 3

$$\frac{W_a\left(V_{T_Y}^2 - V_{T_X}^2\right)}{2g} = J\,c_p T_{T_X}\left[\left(\frac{P_{T_Y}}{P_{T_X}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] W_a$$

$$\left(\frac{P_{T_Y}}{P_{T_X}}\right)^{\frac{\gamma-1}{\gamma}} = 1 + \frac{\left(V_{T_Y}^2 - V_{T_X}^2\right)}{2gJ\,c_p T_{T_X}}$$

$$\frac{P_{T_y}}{P_{T_x}} \left[1 + \frac{(V_{T_y}^2 - V_{T_x}^2)}{2gJC_pT_{T_x}}\right]^{\gamma/\gamma-1}$$

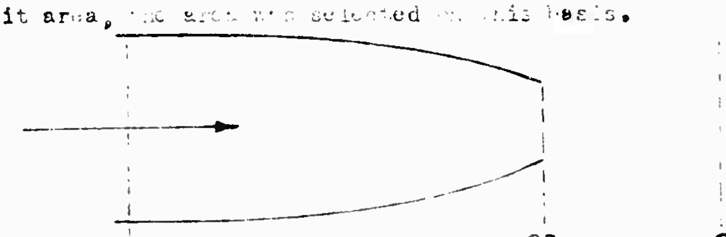
Since $JC_p = R(\gamma/\gamma-1)$, the equation for the pressure ratio developed from station X to station Y may now be written:

$$\frac{P_{T_y}}{P_{T_x}} = \left[1 + \frac{(V_{T_y}^2 - V_{T_x}^2)}{2gRT_{T_x}(\gamma/\gamma-1)}\right]^{\gamma/\gamma-1} \qquad 4$$

[illegible].2.2 Pressure Losses - To determine the pressure losses in the system due to the flow of air through the ducting to the tip burner, a step-by-step analysis was made for each calculated tip burner performance point. The method and data of reference [illegible] were used to evaluate the pressure losses. Pumping gains due to rotor rotation using the method presented in Section [illegible].2.1 and momentum pressure loss (calculated from reference 7) were also taken into consideration. After the pressure available in the tip burner for combustion was determined, the tip burner performance was evaluated in the manner discussed below.

[illegible].2.3 Design Condition - A design condition was first selected which was the basis for determining the nozzle exit area of the tip burner. The design condition chosen was a corrected rotor speed ($N/\sqrt{\theta}$) of 1[illegible],[illegible]00

operating at a [illegible] pressure ratio (P_{23}/P_{T22}) [illegible] is approximately [illegible] efficiency [illegible].
This pressure [illegible] is sufficiently below the compressor stall to indicate a safe operating point. Since [illegible] this design condition indicates the pressure is sufficient to maintain sonic velocity through the nozzle exit area, the area was selected on this basis.



$$P v = R T$$

$$v = \frac{RT}{P} = \frac{AV}{W_g}$$

$$\frac{W_g R T_{23}}{P_{23}} = A_{23} V_{23}$$

For sonic velocity at nozzle exit

$$V_{23} = \sqrt{\gamma g R T_{23}} \qquad 6$$

From critical pressure [illegible] it follows

$$\frac{P_{23}}{P_{T22}} = \left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}$$

$$P_{23} = P_{T22}\left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1} \qquad 7$$

Substituting equations 6 and 7 into equation [illegible] the following expression is obtained for the nozzle area.

$$\frac{W_g R T_{23}}{P_{T22}\left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}} = A_{23}\sqrt{\gamma g R T_{23}} \qquad 8$$

$$A_{23} = \frac{W_g R T_{23}}{P_{T22}\left(2/\gamma+1\right)^{\gamma/\gamma-1}\sqrt{\gamma g R T_{23}}} \qquad 9$$

In view of [illegible] burning efficiency [illegible] that temperatures [illegible] 4,000° Rankine will be obtained in the combustion chamber. Test data [illegible] reported in ref[illegible] 3 indicates burner temperatures of this order and higher. [illegible] nozzle exit area was determined [illegible] maximum [illegible] a total temperature [illegible],000° R. Internal [illegible] layer air cooling [illegible] wall. [illegible] pressure [illegible].

[illegible] were [illegible] and [illegible] temperature at [illegible]:

$$T_T = T\left(1 + \frac{\gamma-1}{2} M^2\right) \qquad 10$$

Since $M = 1.0$

$$T_{23} = 4000\left(\frac{2}{\gamma+1}\right)$$

From equation 9, the nozzle area now becomes:

$$A_{z3} = \frac{W_{a_g} R(4000)\left(\frac{2}{\gamma+1}\right)}{P_{T_{22}}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}\sqrt{\gamma g R(4000)\left(\frac{2}{\gamma+1}\right)}} \qquad 11$$

$$f/a = \frac{C_p \, \Delta T}{h_v \, \eta_B}$$

Assume a burning efficiency of 90% and a lower heating value of gasoline = 18,000 BTU/#.

$$f/a = \frac{C_p \, \Delta T}{16{,}200} \qquad 12$$

Since the values of γ and C_p are dependent upon temperature and fuel-air ratio it is now necessary to make successive approximations for fuel-air ratio and cycle through equations 11 and 12 until both equations are satisfied.

$P_{T_{22}}$ is determined from the duct analysis as described in section 5.2.2 and a trial and error solution is readily made since there is only one fuel-air ratio that will give a total temperature of 4000°R.

On this basis a total nozzle area of 0.938 square feet was determined. This total nozzle area is divided by the number of tip burners to obtain the area per burner. For the six burners the effective nozzle exit area per burner is 22.5 in.^{2} or 5.35 in. in diameter.

5.2.4 **Performance Calculations** - For other corrected compressor speeds and pressure ratios the combustion temperature may be determined since the area has been determined. Transposing equation 8:

$$\frac{T_{23}}{\sqrt{T_{23}}} = \frac{A_{23}\sqrt{\gamma g R}\; P_{T22}\left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}}{W_g\, R}$$

$$T_{23}\left[\frac{A_{23}\sqrt{\gamma g R}\; P_{T22}\left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}}{W_g\, R}\right]^2 \qquad 13$$

Using equation 12 and 13 and determining P_{T22} from the rotor duct analysis T_{23} may be determined for any compressor condition. Although equation 13 applies only when P_{T23} is above the critical pressure ratio, this condition covers most of the system operating range.

Fuel flow is determined by:

$$W_f = f/a\, W_a = \frac{C_p\, \Delta T}{16{,}200}\, W_a \qquad 14$$

Total temperature at the nozzle exit for sonic velocity is

$$T_{T23} = T_{23}\left(\frac{\gamma+1}{2}\right) \qquad 15$$

The jet velocity is obtained from equation 6. Jet thrust is obtained as follows:

$$F_J = \eta_N \frac{W_g}{g} (V_{23} - V_T) + (P_{23} - P_0) A_{23} \qquad 16$$

η_N = nozzle efficiency (assumed .95)

A sample calculation is presented in table 7. The first section of the calculation is the rotor system duct analysis to determine the pressure available for burning. The latter part of the calculation presents the tip burner performance for the available pressure. It was assumed that the division of air flow through the two flow passages in the rotor blade (station 17 through 23) was equal, even though the cross-sectional areas are slightly different (22.1 and 24.3 square inches per blade). The actual division of the air flow will be governed by the back pressure of each tip burner due to burning. The total temperature, fuel flow, and jet thrust were calculated for each of the two tip burners and the average total temperature was used for the total temperature of the gas.

Curves of corrected performance over a range of thrust values are presented in figures 26 and 27. Corrected values are presented in the general curves since they are independent of the compressor inlet conditions. The correction factors used are the standard factors used in correction of jet engine performance. Reference 10 presents the derivation of these factors. These factors are:

$\delta = P_{T_2}/14.7$ where P_{T_2} is expressed in PSIA

$\theta = T_{T_2}/518.4$ where T_{T_2} is expressed in degrees Rankine

Several numerical examples were checked for various altitudes within the performance range of Model 78. Agreement of corrected performance with that determined by using the actual temperature and pressure was obtained.

Actual tip burner thrust and overall fuel consumption are presented in figures 28 through 31 for the anticipated operating range of the tip burners.

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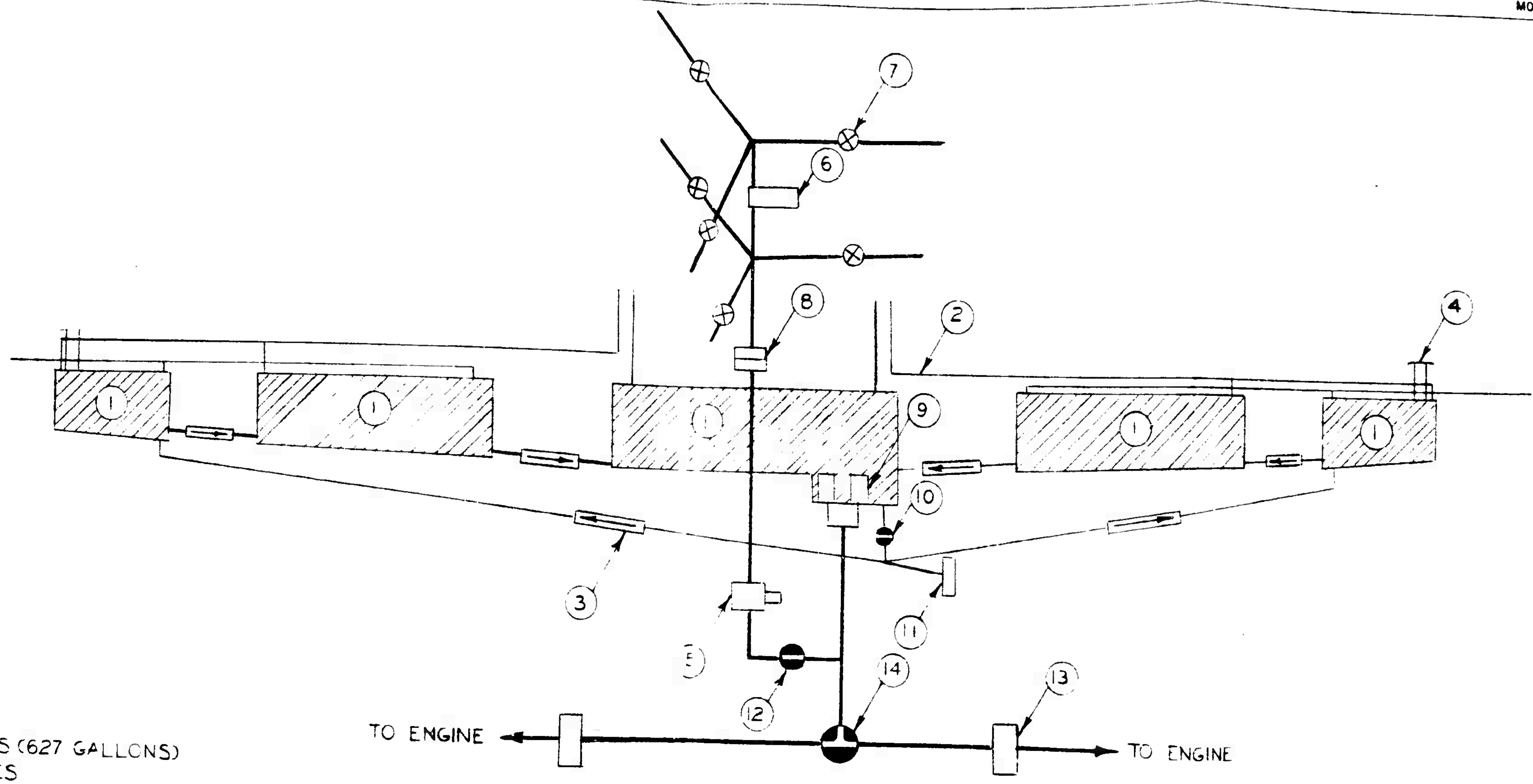

1 FUEL CELLS (627 GALLONS)
2 VENT LINES
3 CHECK VALVES
4 FILLER NECK
5 ROTOR DRIVEN PUMP-GOVERNOR UNIT
6 SHUT OFF VALVE (FOR SINGLE ENGINE HELICOPTER FLIGHT ONLY)
7 ORIFICE
8 ROTARY JOINT
9 BOOST PUMP
10 SHUT OFF VALVE - NORMALLY CLOSED
11 PRESSURE FUELING & DEFUELING FITTING
12 SHUT OFF VALVE
13 FILTER
14 SELECTOR VALVE-LEFT-RIGHT-BOTH-OFF

MODEL 78
FUEL SYSTEM SCHEMATIC

FIG 1

Date 20 December 1950

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Model 78

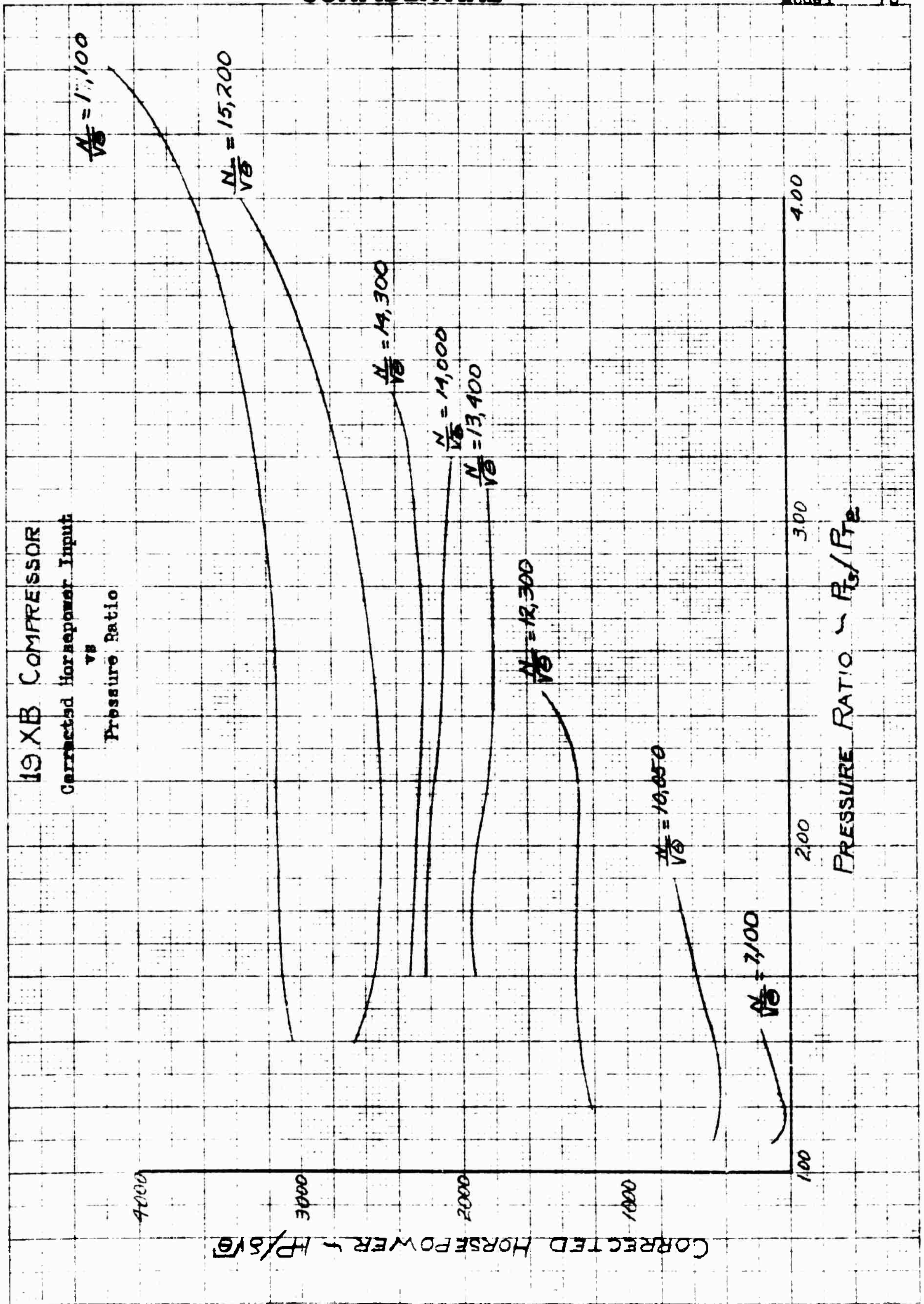

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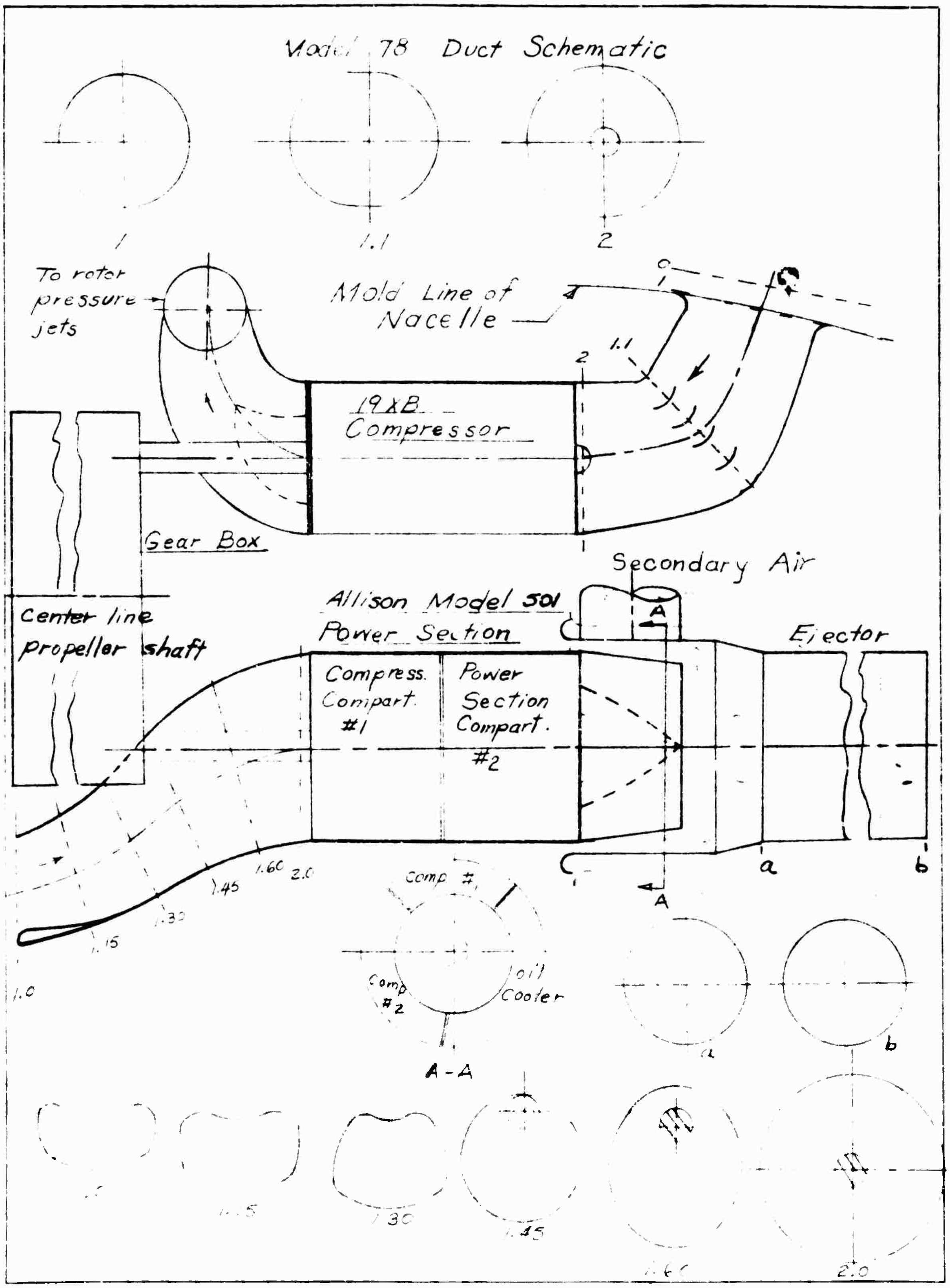
FIG. 2


Model 78 Duct Schematic
1
1.1
2
To rotor pressure jets
Mold Line of Nacelle
19XB Compressor
Gear Box
Center line propeller shaft
Secondary Air
Allison Model 501 Power Section
Compress. Compart. #1
Power Section Compart. #2
Ejector
A
a
b
1.0
1.15
1.30
1.45
1.60
2.0
Comp #1
Comp #2
oil Cooler
A - A
1.30
1.45
2.0

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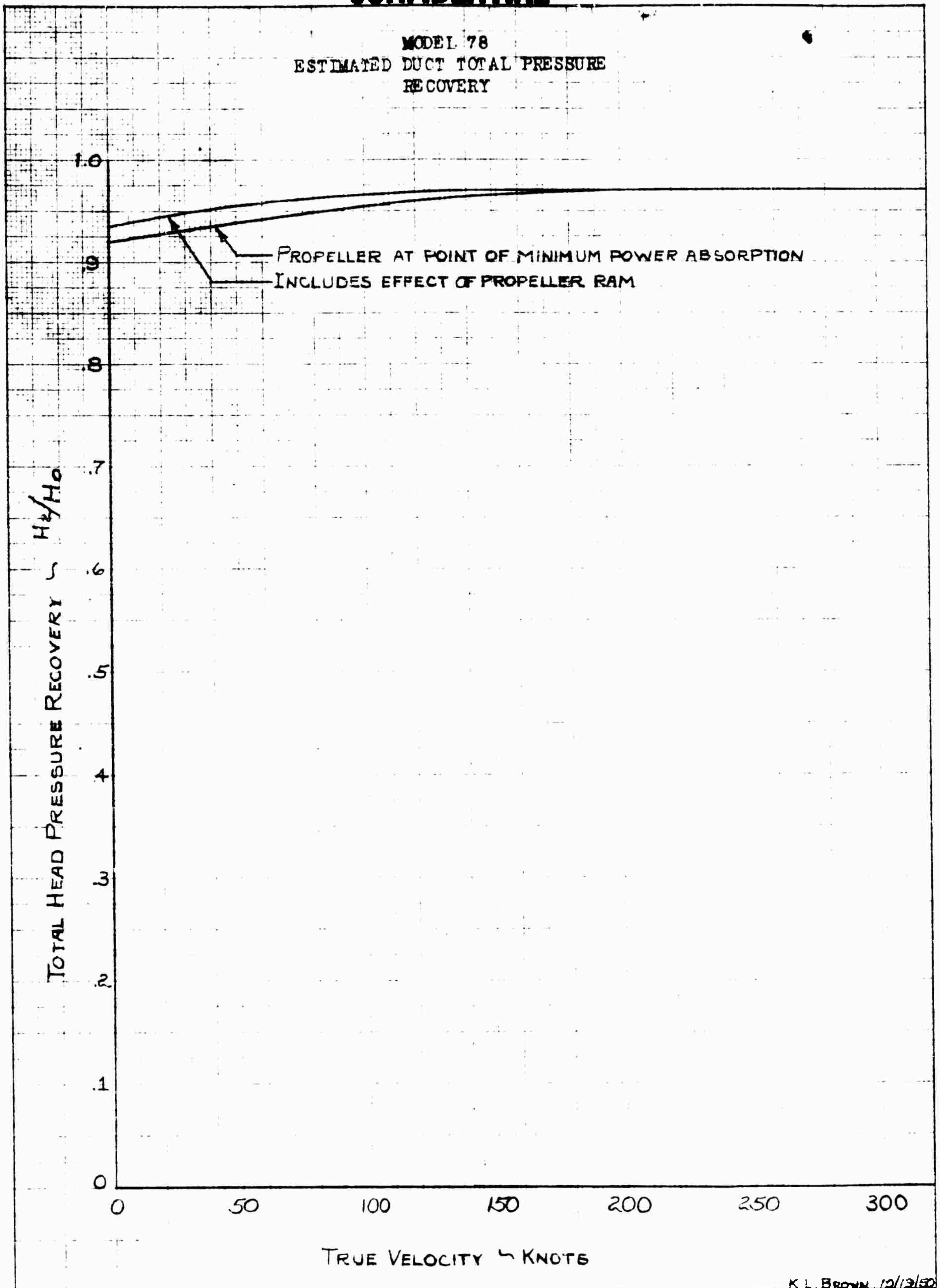

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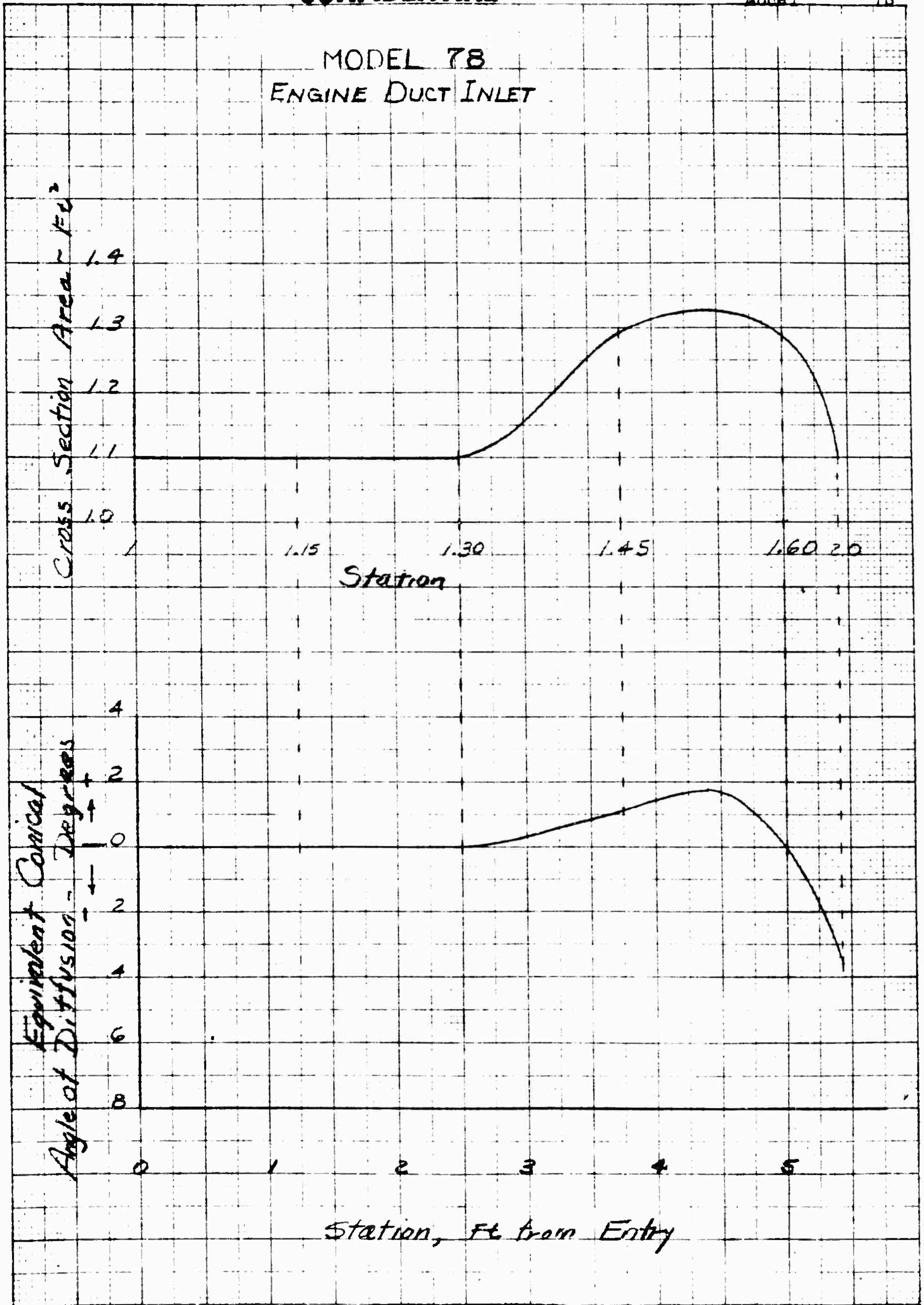
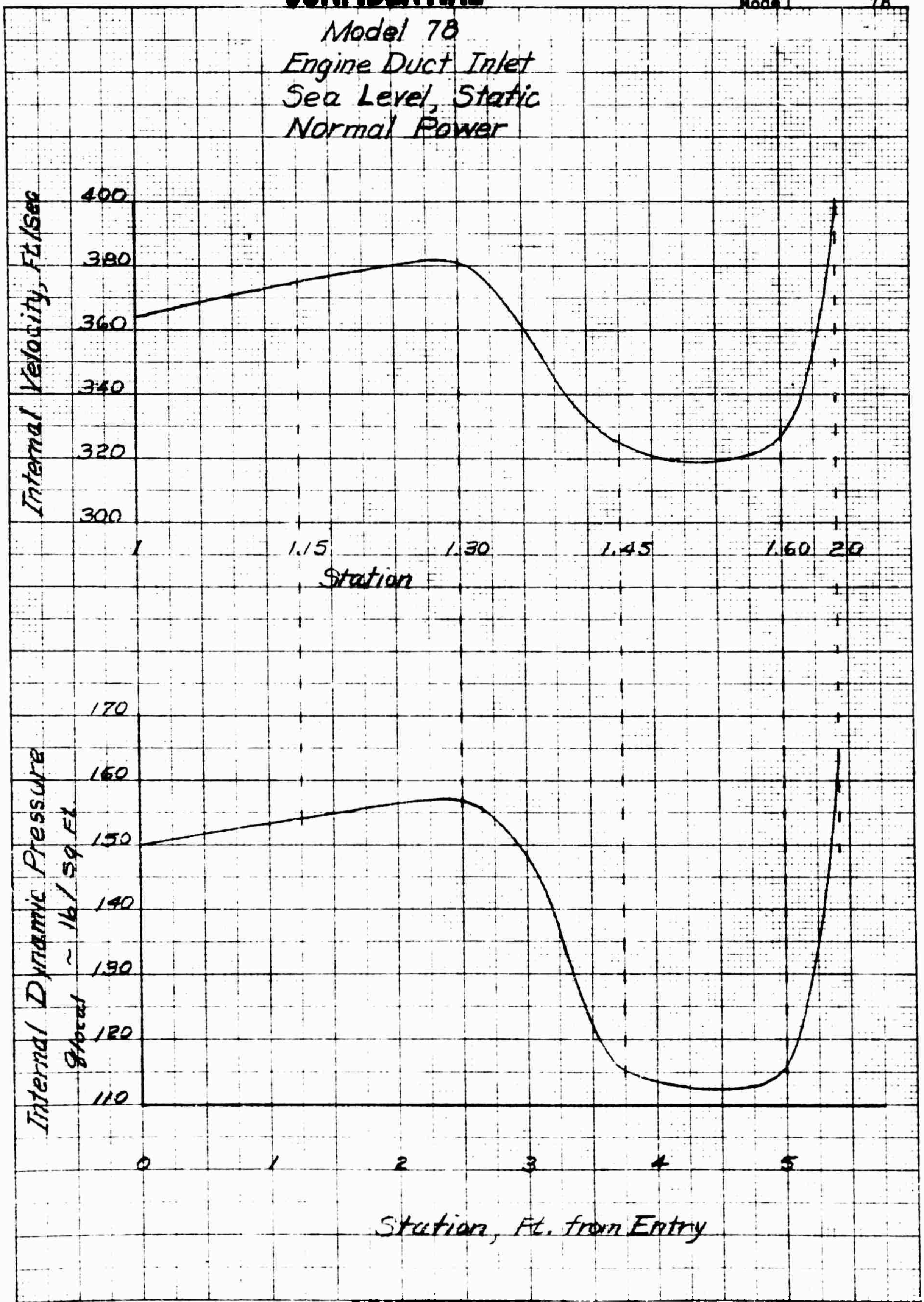
FIG. 4


MODEL 78
ENGINE DUCT INLET
Cross Section Area ~ Ft²
1.4
1.3
1.2
1.1
1.0
1
1.15
1.30
1.45
1.60
2.0
Station
Equivalent Conical
Angle of Diffusion - Degrees
4
2
0
2
4
6
8
0
1
2
3
4
5
Station, Ft from Entry


Model 78
Engine Duct Inlet
Sea Level, Static
Normal Power
Internal Velocity, Ft/sec
400
380
360
340
320
300
1
1.15
1.30
1.45
1.60
2.0
Station
Internal Dynamic Pressure
q_{local} ~ lb/sq ft
170
160
150
140
130
120
110
0
1
2
3
4
5
Station, Ft. from Entry

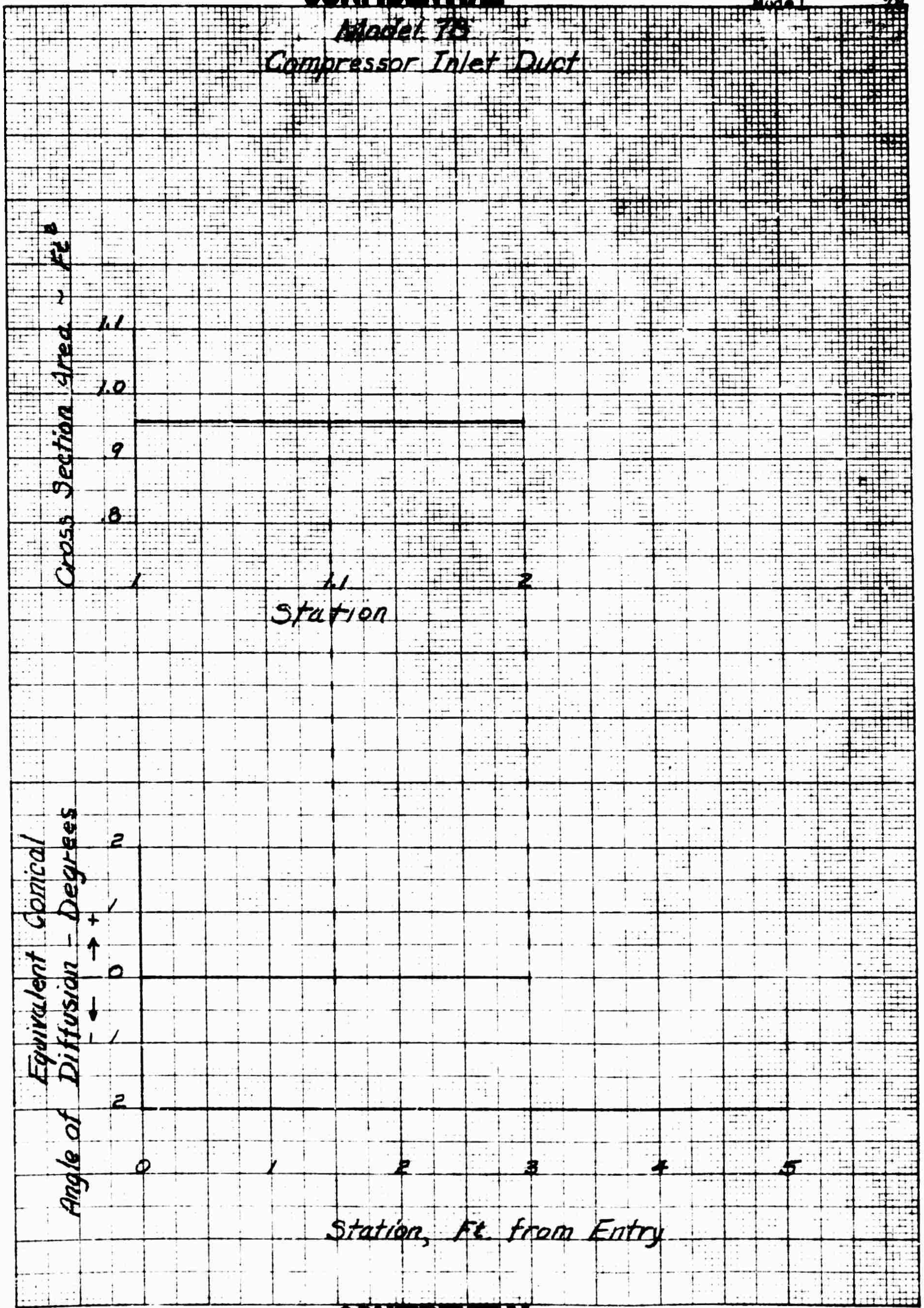

Model 78
Compressor Inlet Duct
Cross Section Area ~ Ft²
1.1
1.0
.9
.8
1
1.1
2
Station
Equivalent Conical
Angle of Diffusion - Degrees
2
1
+
0
-
1
2
0
1
2
3
4
5
Station, Ft. from Entry

FIG. 7

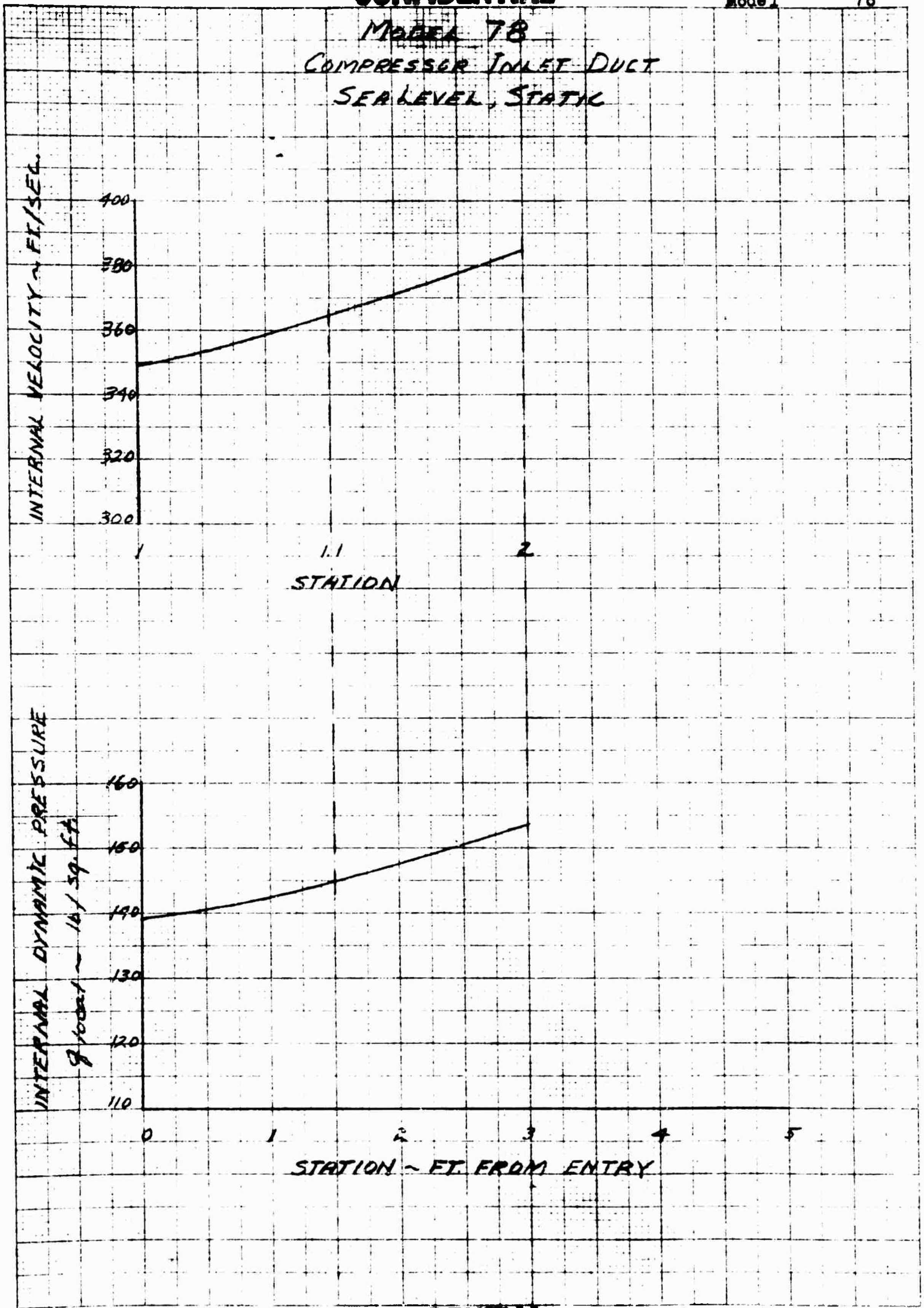

MODEL 78
COMPRESSOR INLET DUCT
SEA LEVEL, STATIC
INTERNAL VELOCITY ~ FT/SEC
400
380
360
340
320
300
1
1.1
2
STATION
INTERNAL DYNAMIC PRESSURE
q local ~ lb/sq ft
160
150
140
130
120
110
0
1
2
3
4
5
STATION ~ FT FROM ENTRY

FIG. 8

Condition: Sea Level, Static, Normal Power (14,000 RPM)

$F = 575\#$, Nozzle Efficiency, $\eta = .95$

$W_a = 28.45\ \#/sec$, $W_f = 1473\ \#/hr = .409\ \#/sec$

$W_f/W_a = .0144$, $\gamma = 1.353$, $T_T = 1295\ ^\circ R$

$$F = \eta \frac{W}{g} V_j - \frac{W_a}{g} V_o = .95 \times \frac{28.45 + .409}{32.2} \times V_j - 0 = 575$$

$$V_j = \frac{575 \times 32.2}{.95\,(28.859)} = 676\ Ft/sec$$

From the ideal jet velocity equation, Solve for the nozzle pressure ratio.

$$V = \sqrt{2g R \frac{\gamma}{\gamma - 1} T_T \left[1 - (P_o/P_T)^{\frac{\gamma-1}{\gamma}}\right]}$$

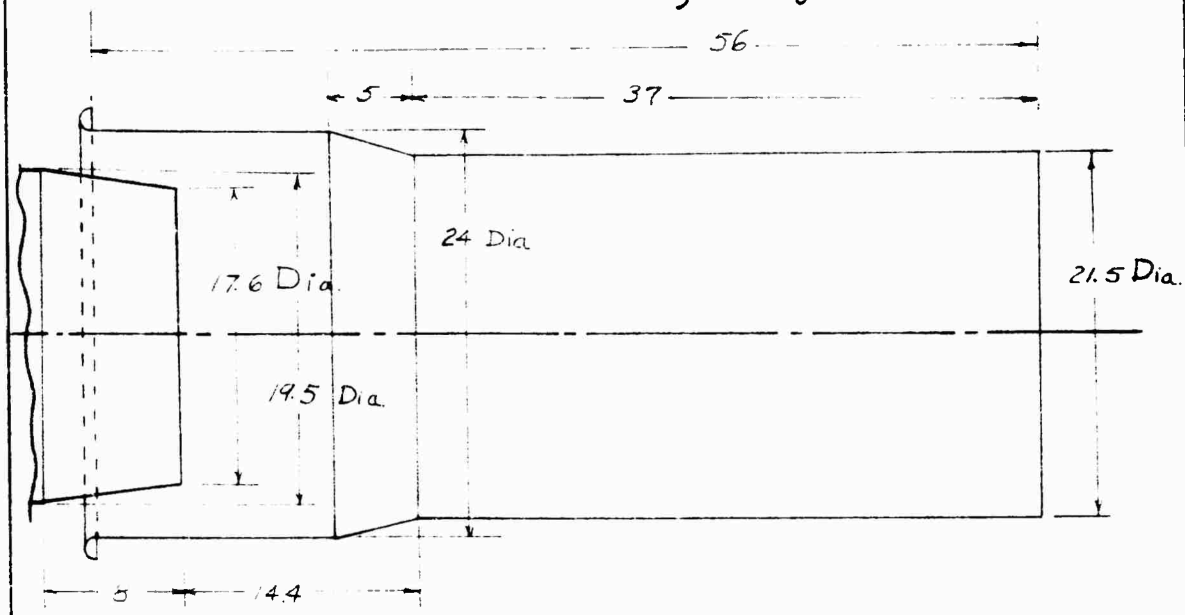
$$\overline{676}^2 = \frac{2 \times 32.2 \times 53.3 \times 1.353 \times 1295}{1.353 - 1} \left[1 - (P_o/P_T)^{\frac{.353}{1.353}}\right]$$

$$P_o/P_T = (.9732)^{3.835} = .90$$

$$P_T/P_o = \frac{1}{.90} = 1.12$$

The exhaust nozzle pressure ratio is 1.12.

Estimated Secondary Weight Flow



The corrected weight flow ratio from reference 4.

$$\frac{W_S}{W_P}\sqrt{\frac{T_S}{T_P}} = .14$$

$$T_S = 520°R$$

$$T_P = 1295°R$$

$$W_S/W_P = .14\sqrt{\frac{T_P}{T_S}} = .14\sqrt{\frac{1295}{520}} = .222$$

$$W_P = 28.45 \text{ lb/sec}$$

$$W_S = .222 \times 28.45 = 6.28 \text{ lb/sec}$$

FIG. 10

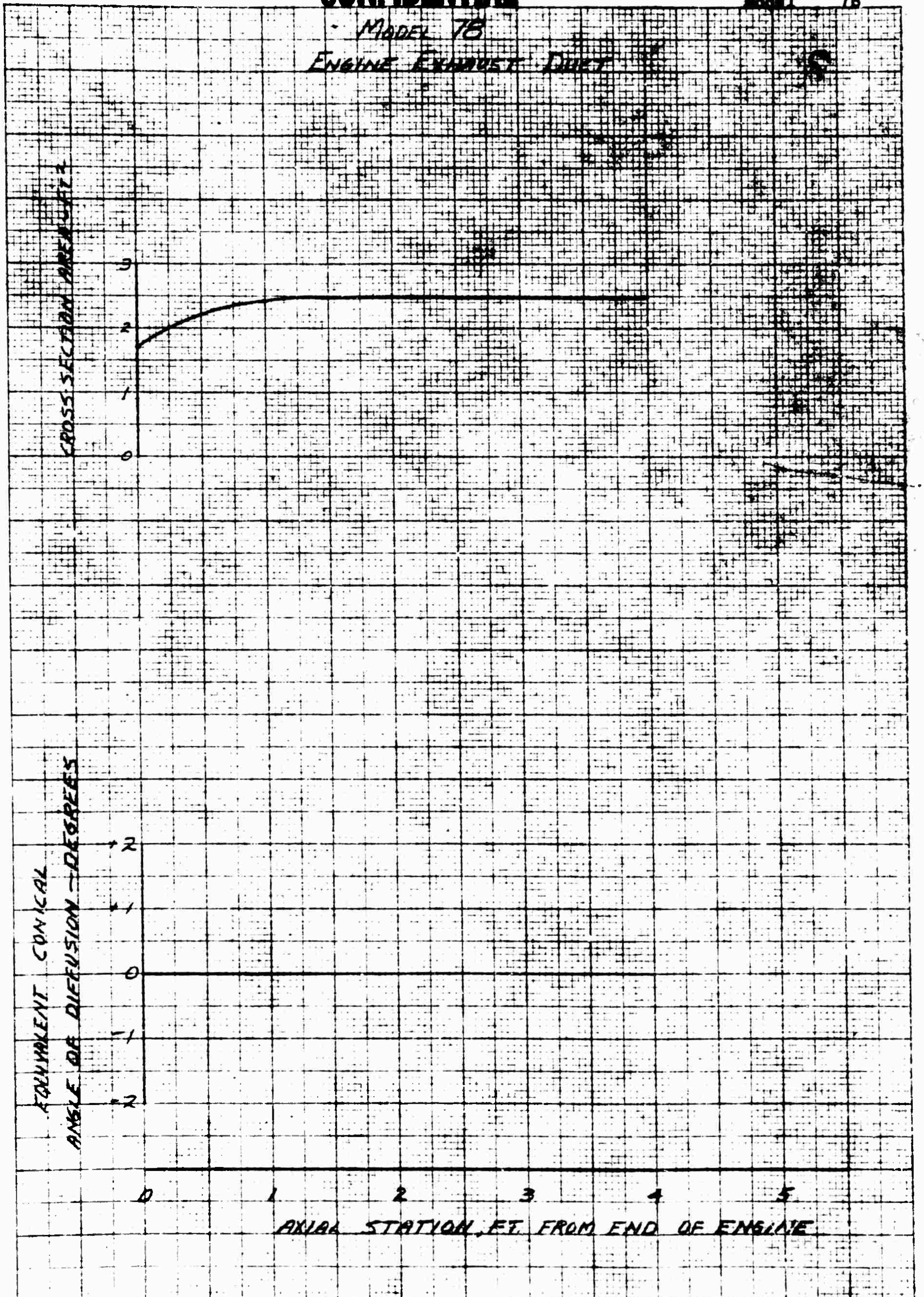

MODEL 78
ENGINE EXHAUST DUCT
CROSS SECTION AREA - FT²
3
2
1
0
EQUIVALENT CONICAL
ANGLE OF DIFFUSION - DEGREES
+2
+1
0
-1
-2
0
1
2
3
4
5
AXIAL STATION, FT. FROM END OF ENGINE

FIG. 11

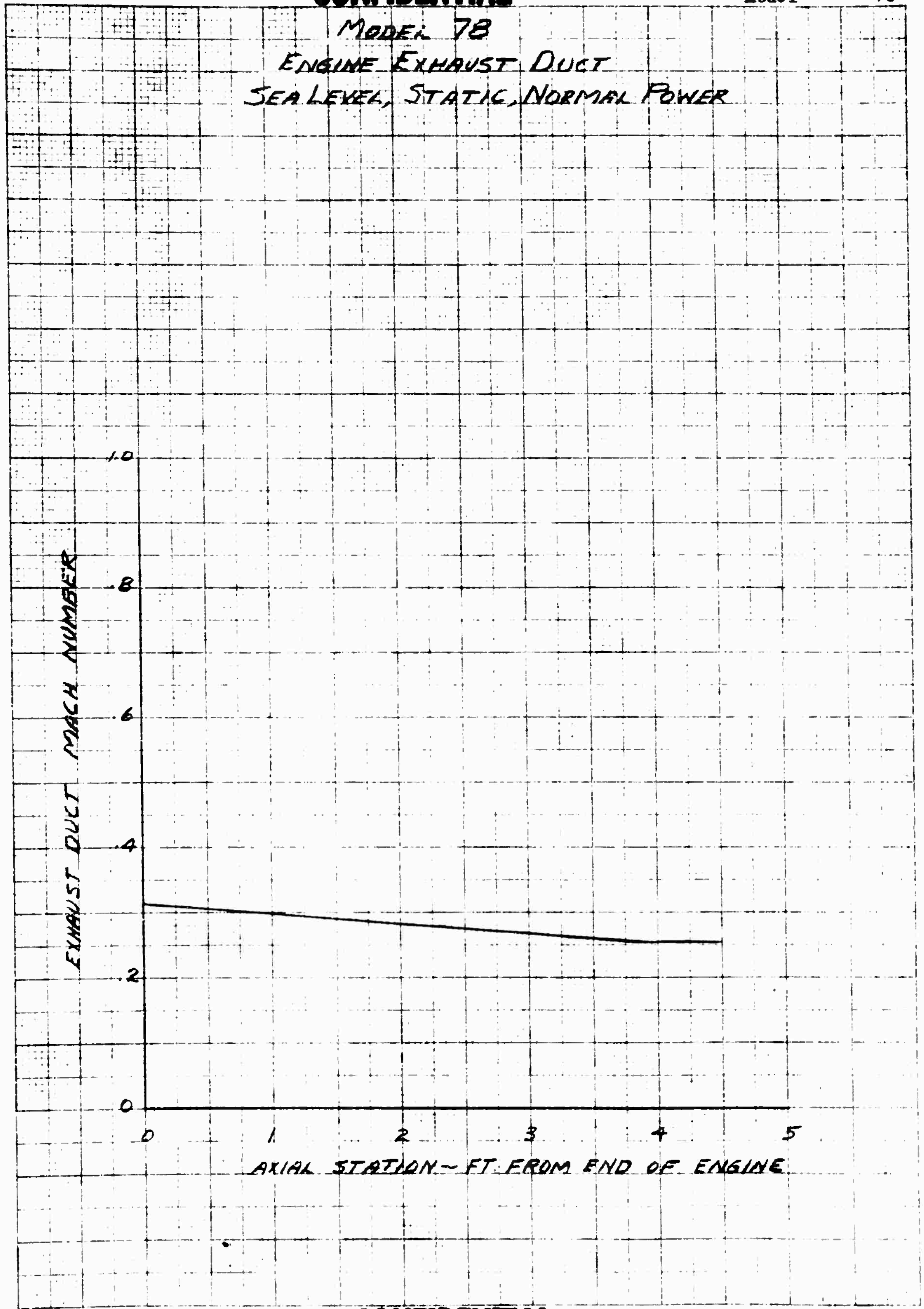

MODEL 78
ENGINE EXHAUST DUCT
SEA LEVEL, STATIC, NORMAL POWER
EXHAUST DUCT MACH NUMBER
1.0
.8
.6
.4
.2
0
0
1
2
3
4
5
AXIAL STATION ~ FT FROM END OF ENGINE

FIG 12

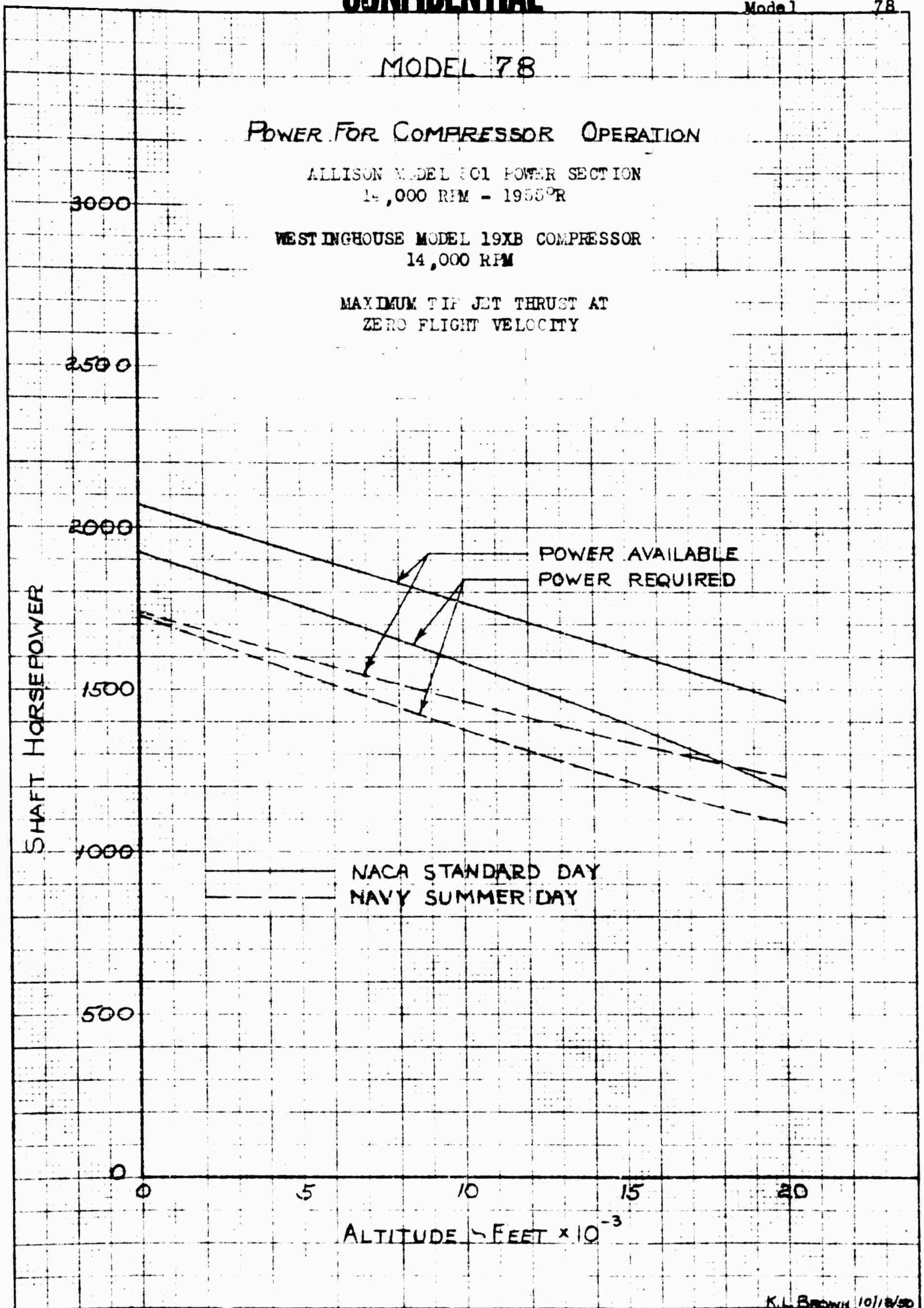
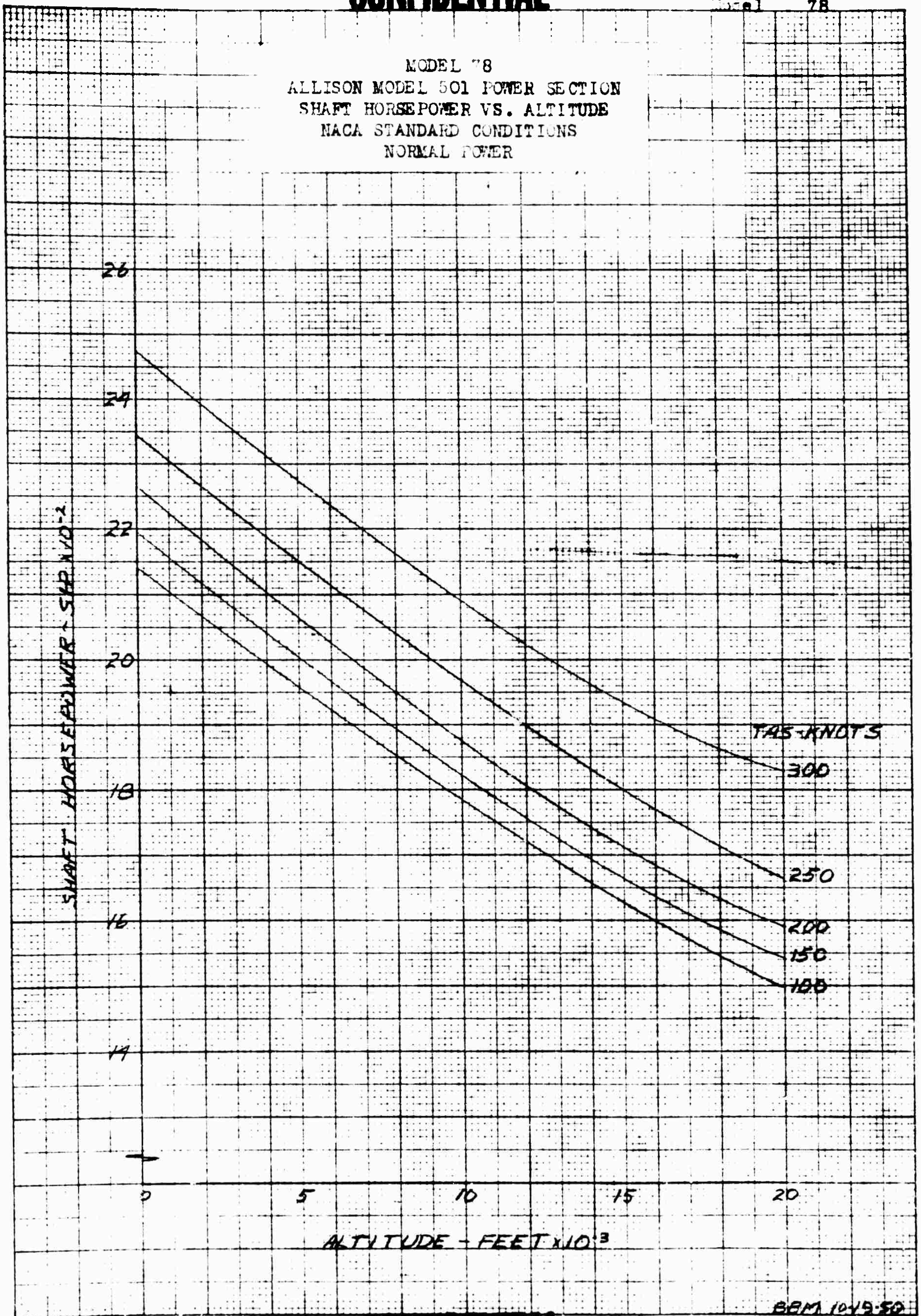

MODEL 78
POWER FOR COMPRESSOR OPERATION
ALLISON MODEL 501 POWER SECTION
14,000 RPM - 1955°R
WESTINGHOUSE MODEL 19XB COMPRESSOR
14,000 RPM
MAXIMUM TIP JET THRUST AT
ZERO FLIGHT VELOCITY
3000
2500
2000
1500
1000
500
0
SHAFT HORSEPOWER
POWER AVAILABLE
POWER REQUIRED
NACA STANDARD DAY
NAVY SUMMER DAY
0
5
10
15
20
ALTITUDE ~ FEET × 10^-3
K.L. Brown 10/18/50

FIG 13


MODEL 78
ALLISON MODEL 501 POWER SECTION
SHAFT HORSEPOWER VS. ALTITUDE
NACA STANDARD CONDITIONS
NORMAL POWER
SHAFT HORSEPOWER - SHP x10^-2
26
24
22
20
18
16
14
TAS-KNOTS
300
250
200
150
100
0
5
10
15
20
ALTITUDE - FEET x10^3
BBM 10-19-50

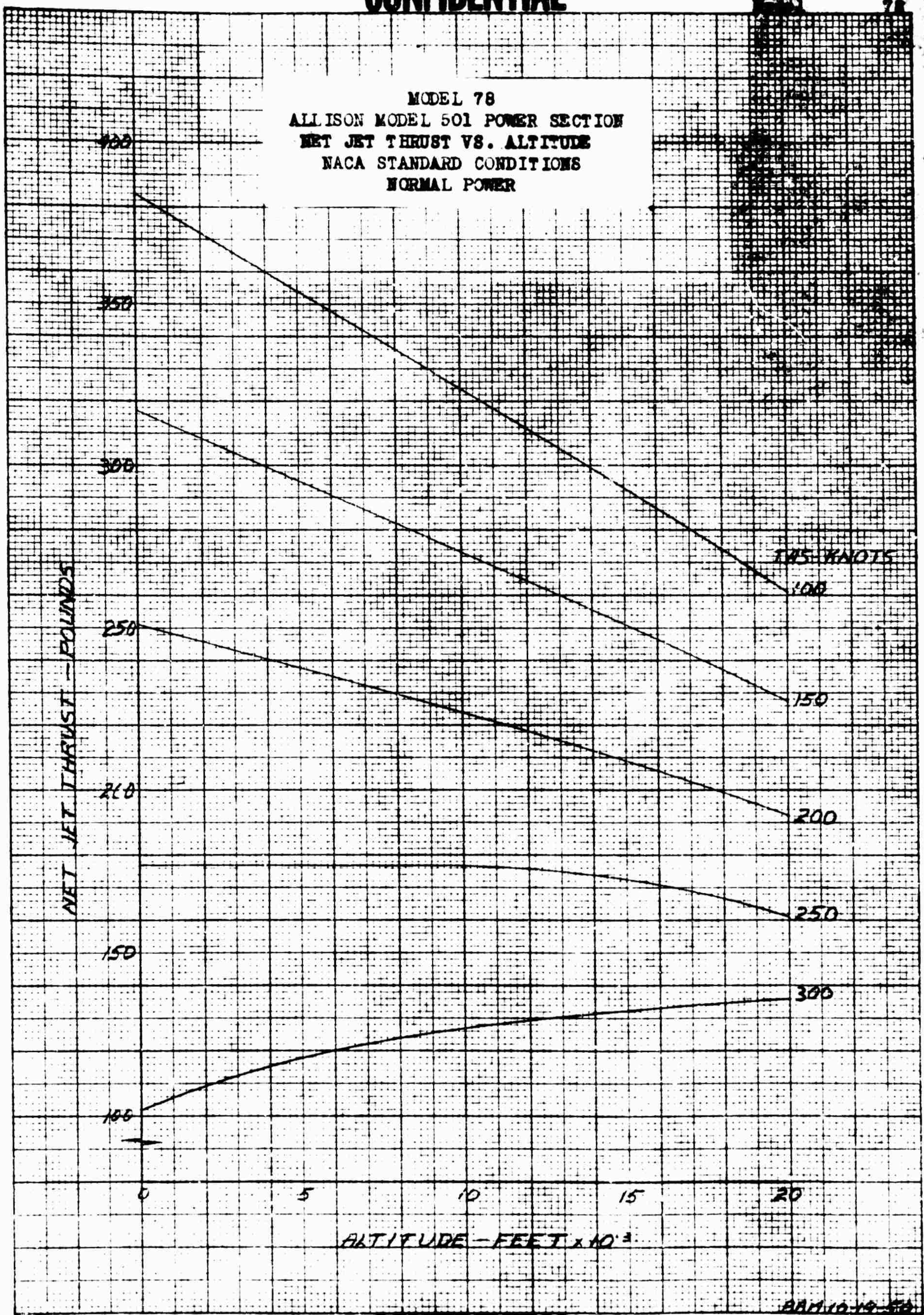

MODEL 78
ALLISON MODEL 501 POWER SECTION
NET JET THRUST VS. ALTITUDE
NACA STANDARD CONDITIONS
NORMAL POWER
NET JET THRUST - POUNDS
400
350
300
250
200
150
100
TAS-KNOTS
100
150
200
250
300
0
5
10
15
20
ALTITUDE - FEET x 10³
BAM 10-19-50

FIG. 15

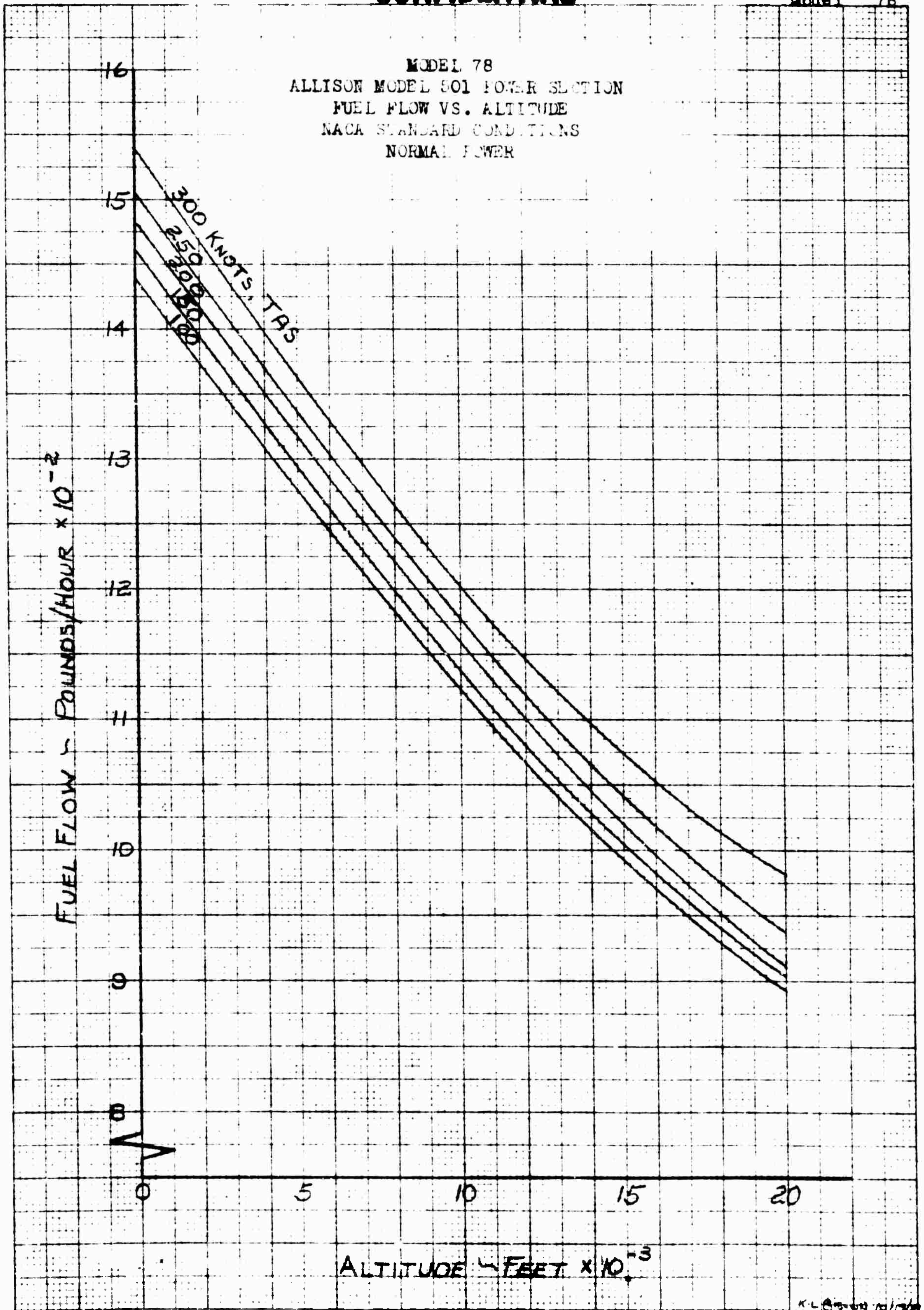

MODEL 78
ALLISON MODEL 501 POWER SECTION
FUEL FLOW VS. ALTITUDE
NACA STANDARD CONDITIONS
NORMAL POWER
300 KNOTS, TAS
250
200
150
100
FUEL FLOW ~ POUNDS/HOUR × 10^-2
16
15
14
13
12
11
10
9
8
0
5
10
15
20
ALTITUDE ~ FEET × 10^-3

FIG. 16

Date 20 December 1950

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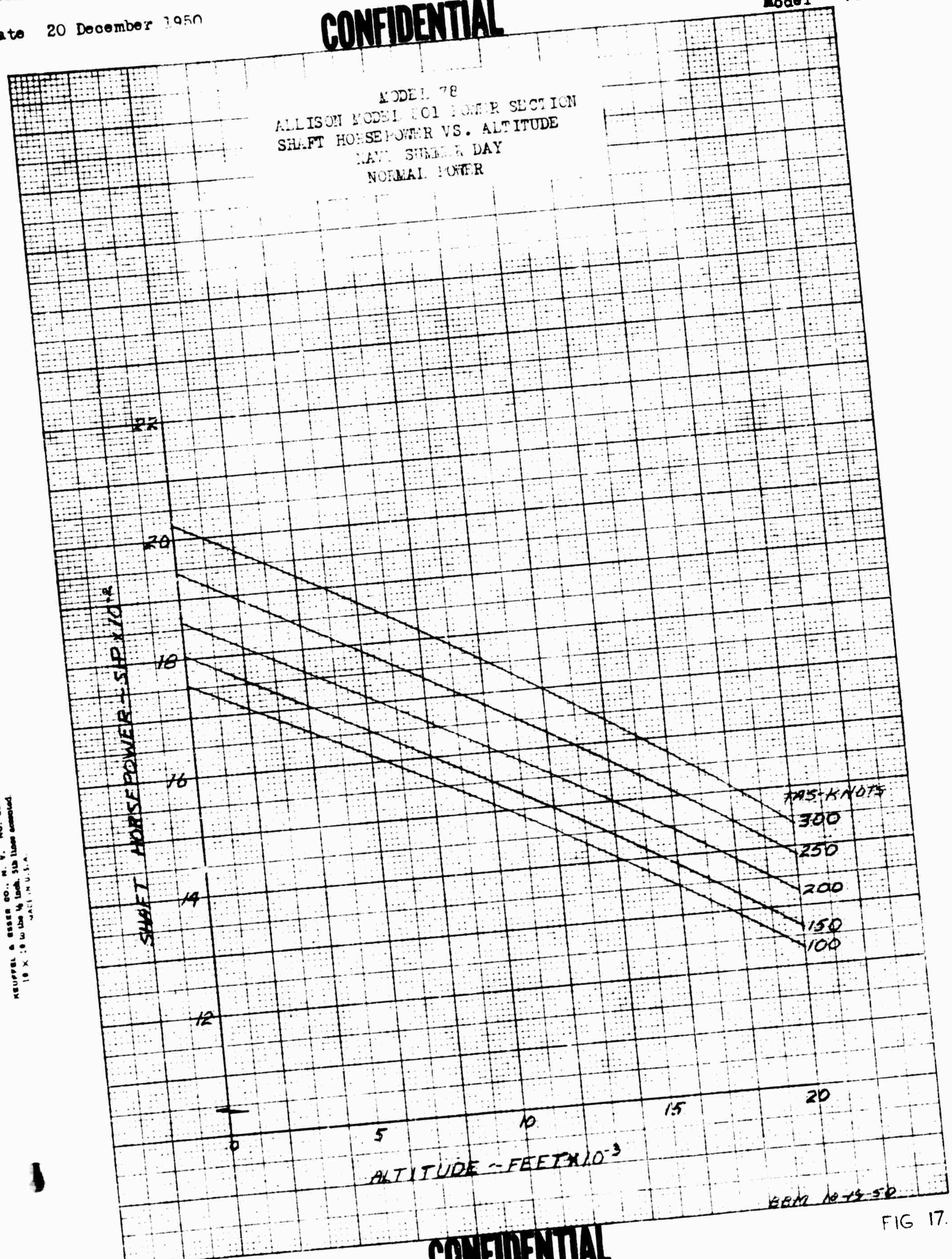

FIG 17.

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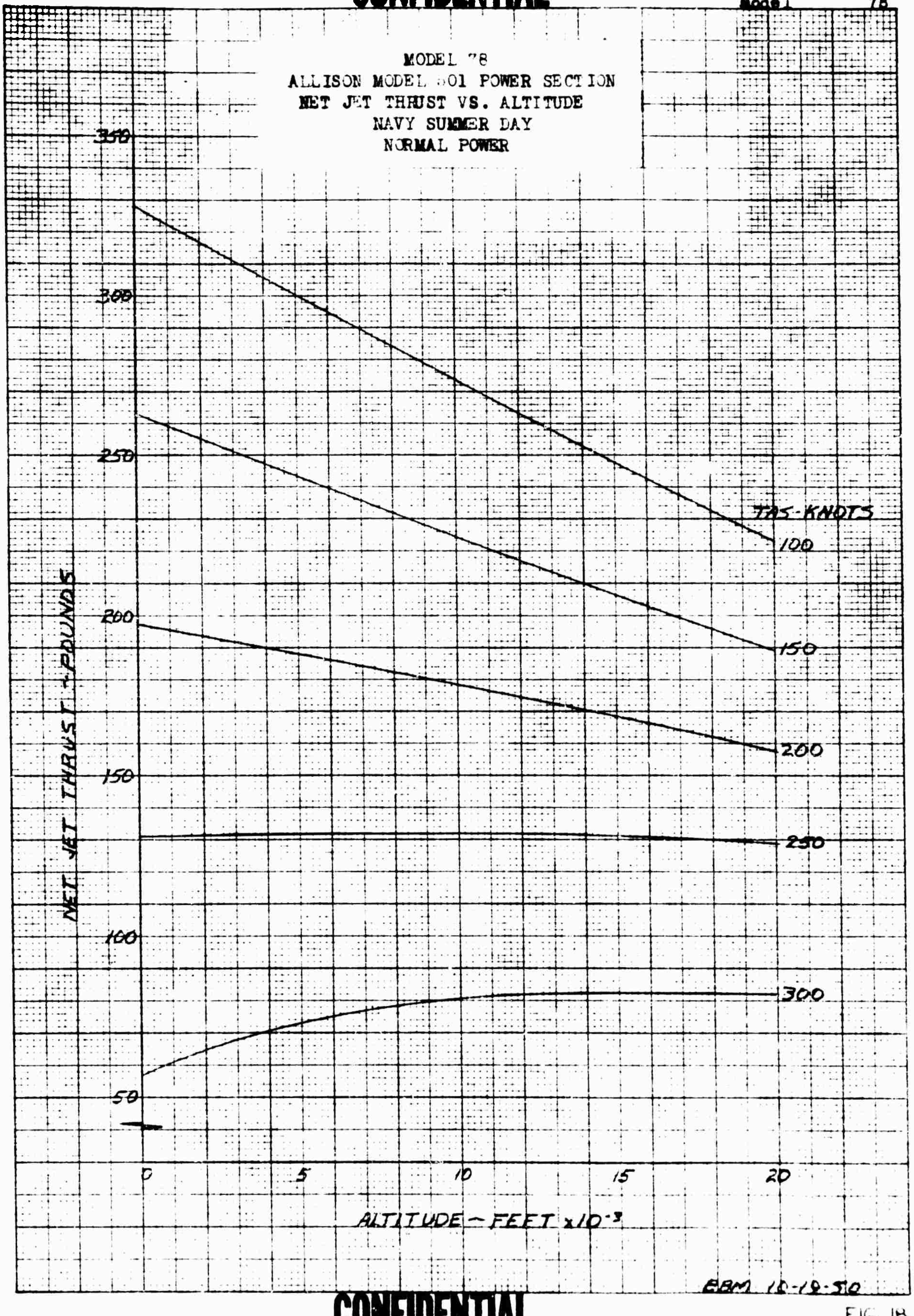
MODEL 78
ALLISON MODEL 501 POWER SECTION
NET JET THRUST VS. ALTITUDE
NAVY SUMMER DAY
NORMAL POWER
NET JET THRUST ~ POUNDS
350
300
250
200
150
100
50
TAS-KNOTS
100
150
200
250
300
0
5
10
15
20
ALTITUDE ~ FEET x10⁻³
EBM 12-19-50

Date 20 December 1950

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Model 78

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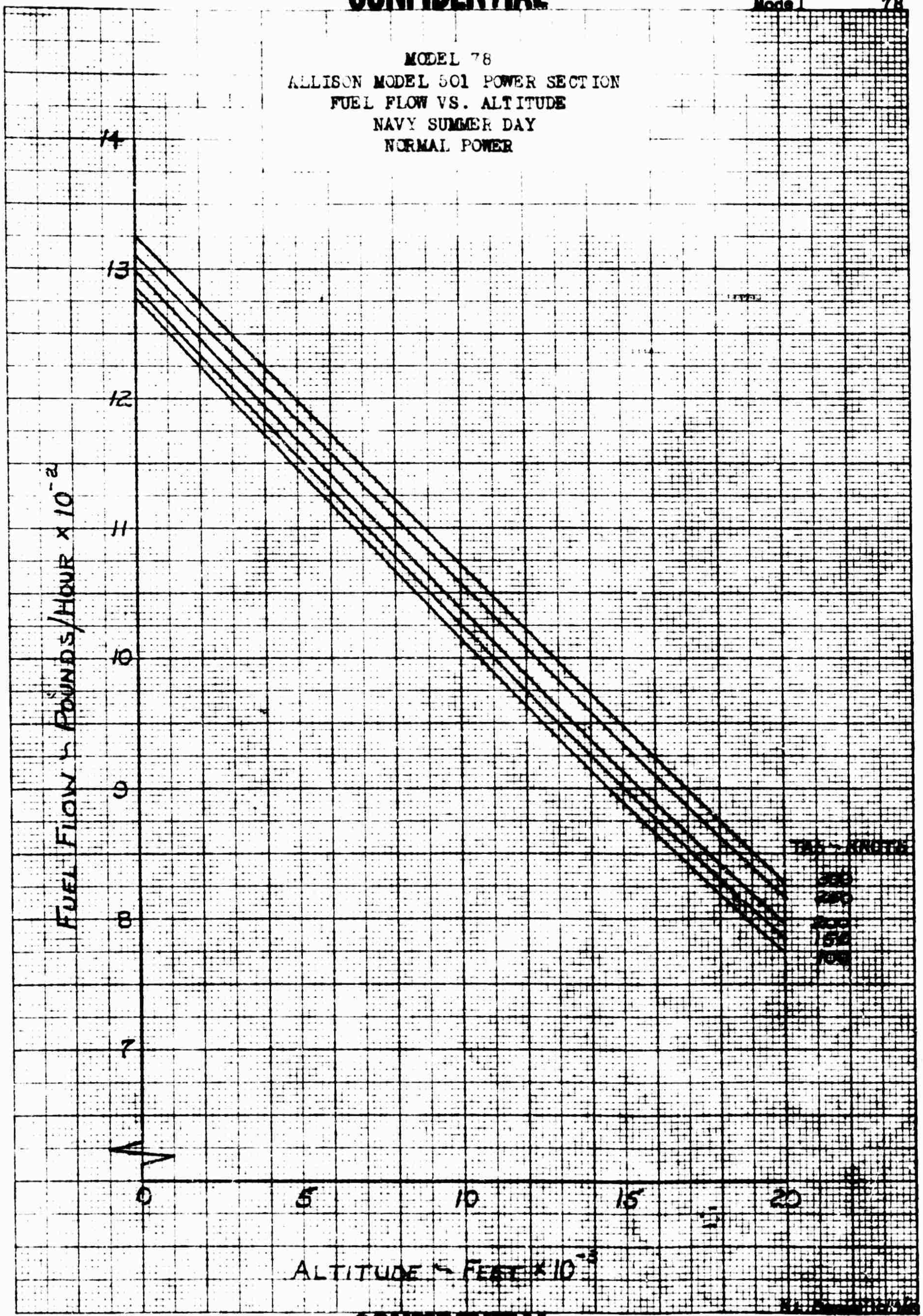

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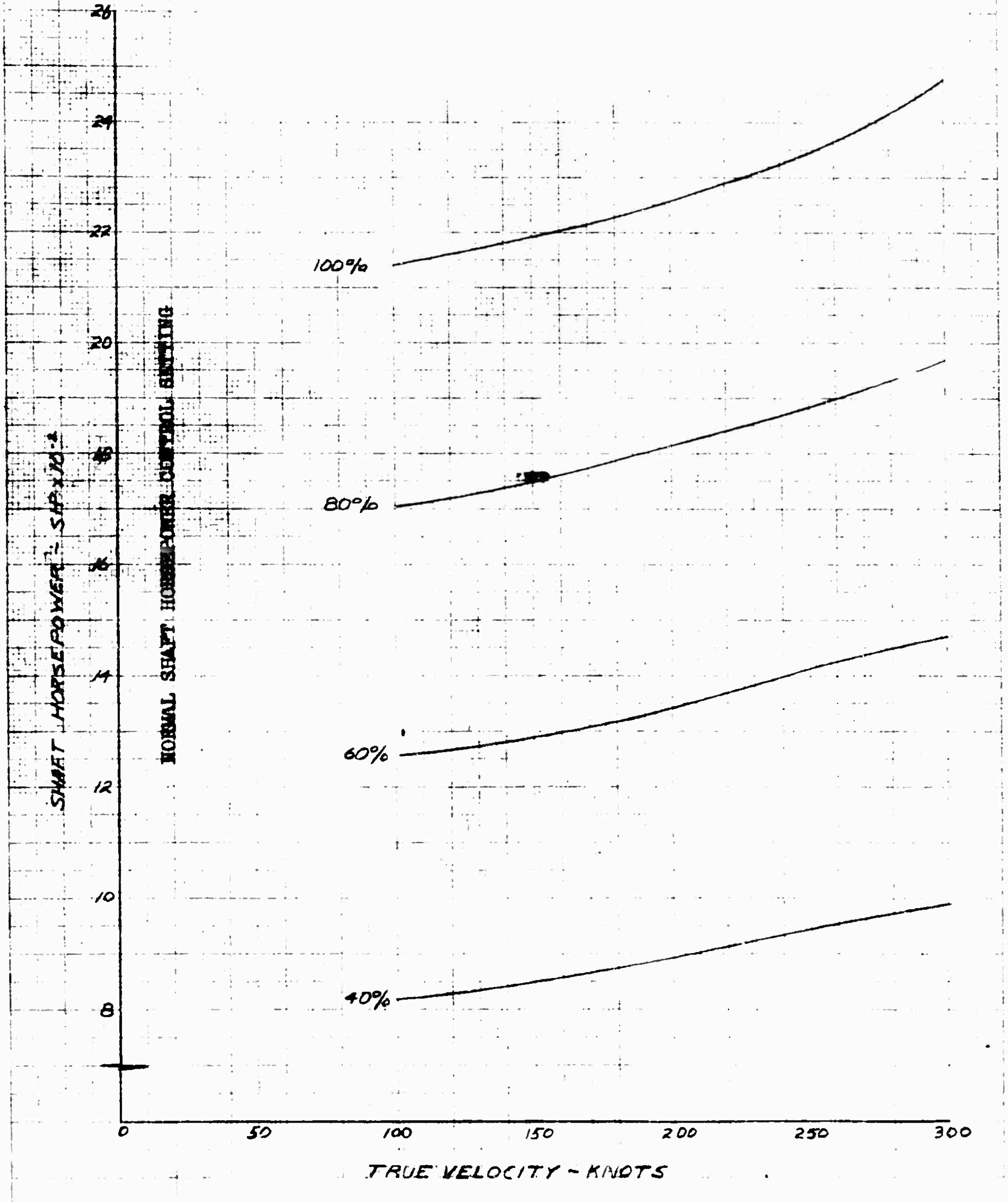
FIG. 19

MODEL 78
ALLISON MODEL 501 POWER SECTION
SHAFT HORSEPOWER VS. VELOCITY
NACA STANDARD CONDITIONS
SEA LEVEL



BBM 10-19-50
FIG 20

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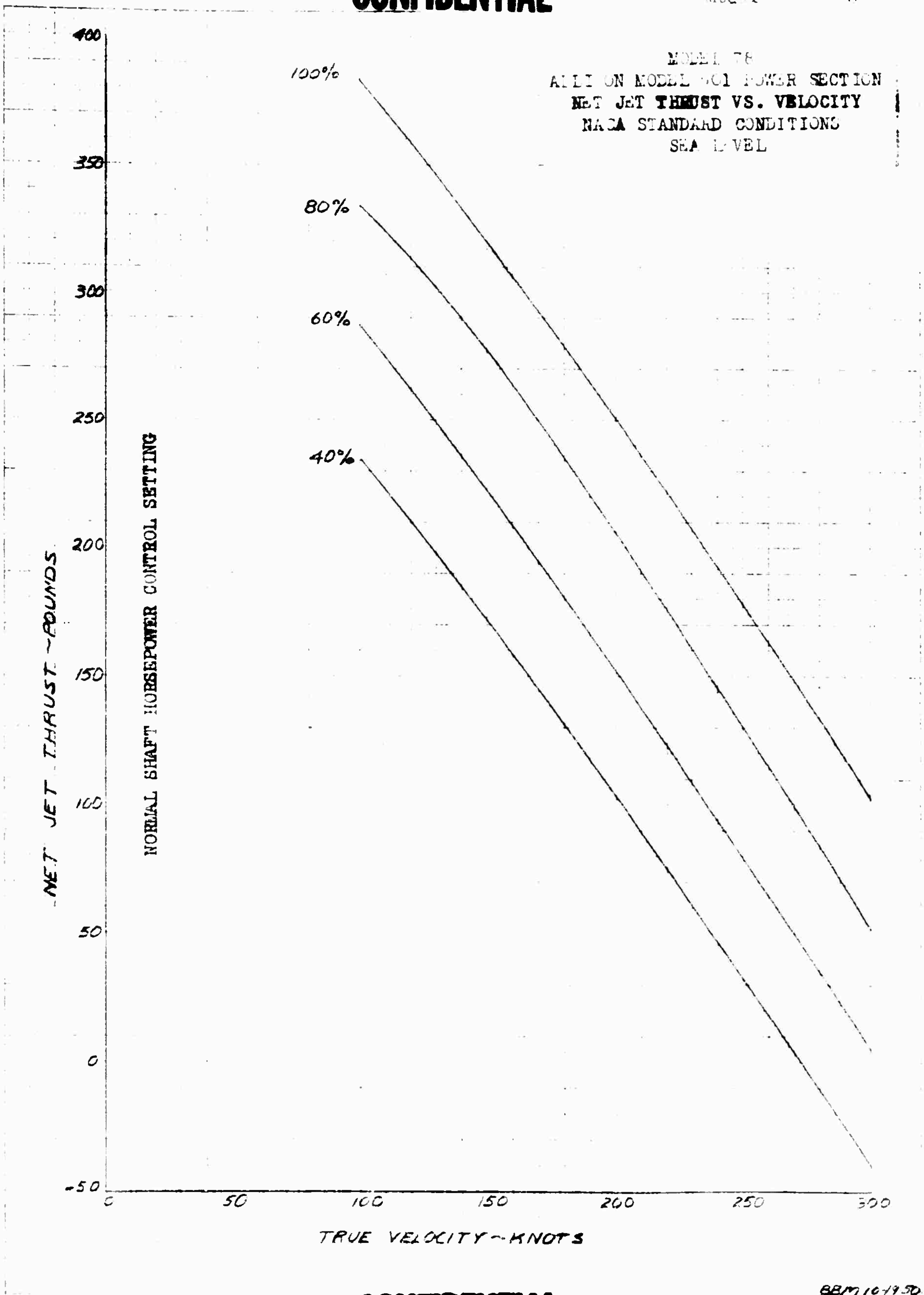

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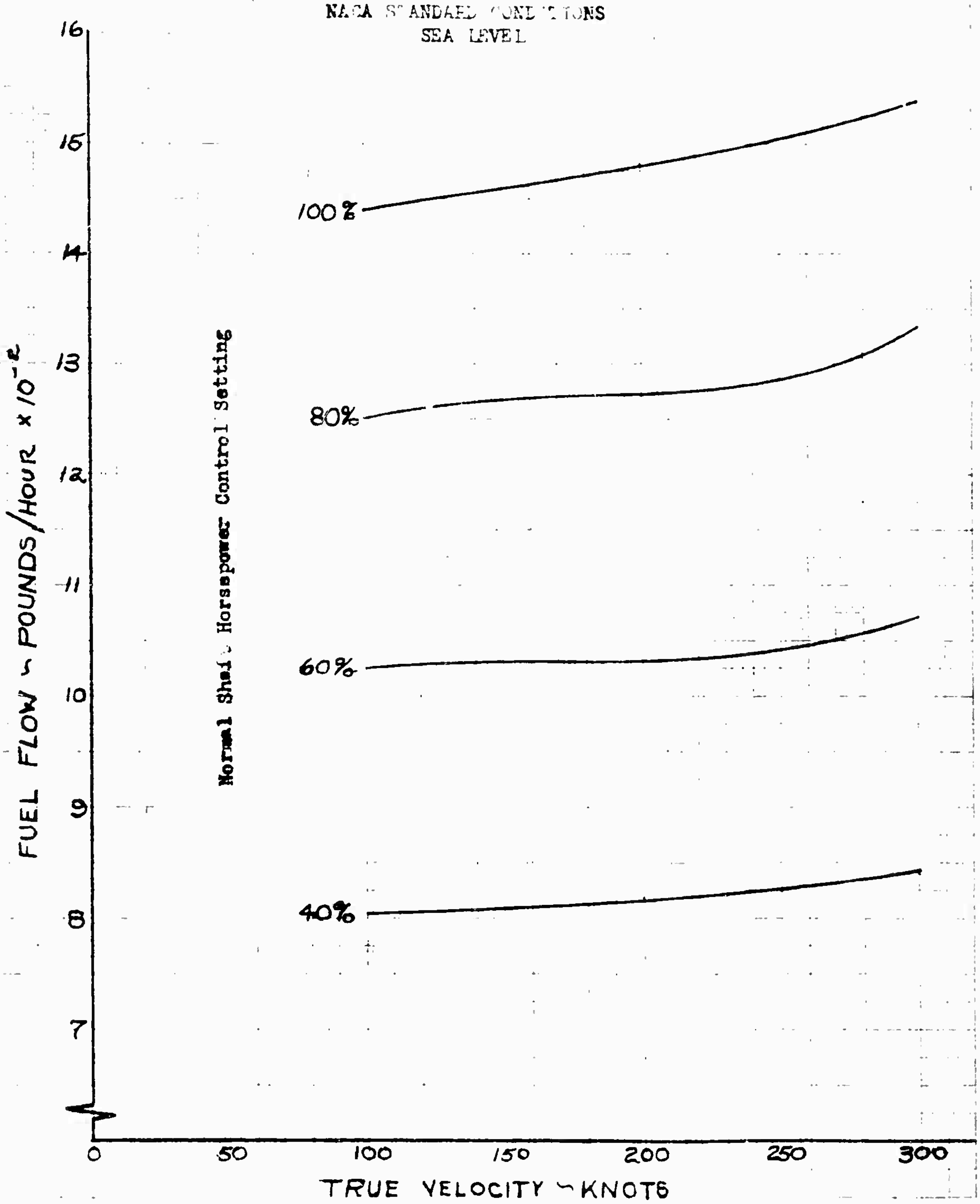
8BM 10-19-50

FIG. 21

MODEL 78
ALLISON MODEL 501 POWER SECTION
FUEL FLOW VS. VELOCITY
NACA STANDARD CONDITIONS
SEA LEVEL



K.L. Brown 10/19/50
FIG. 22

Date 20 December 195[illegible]

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Model 78

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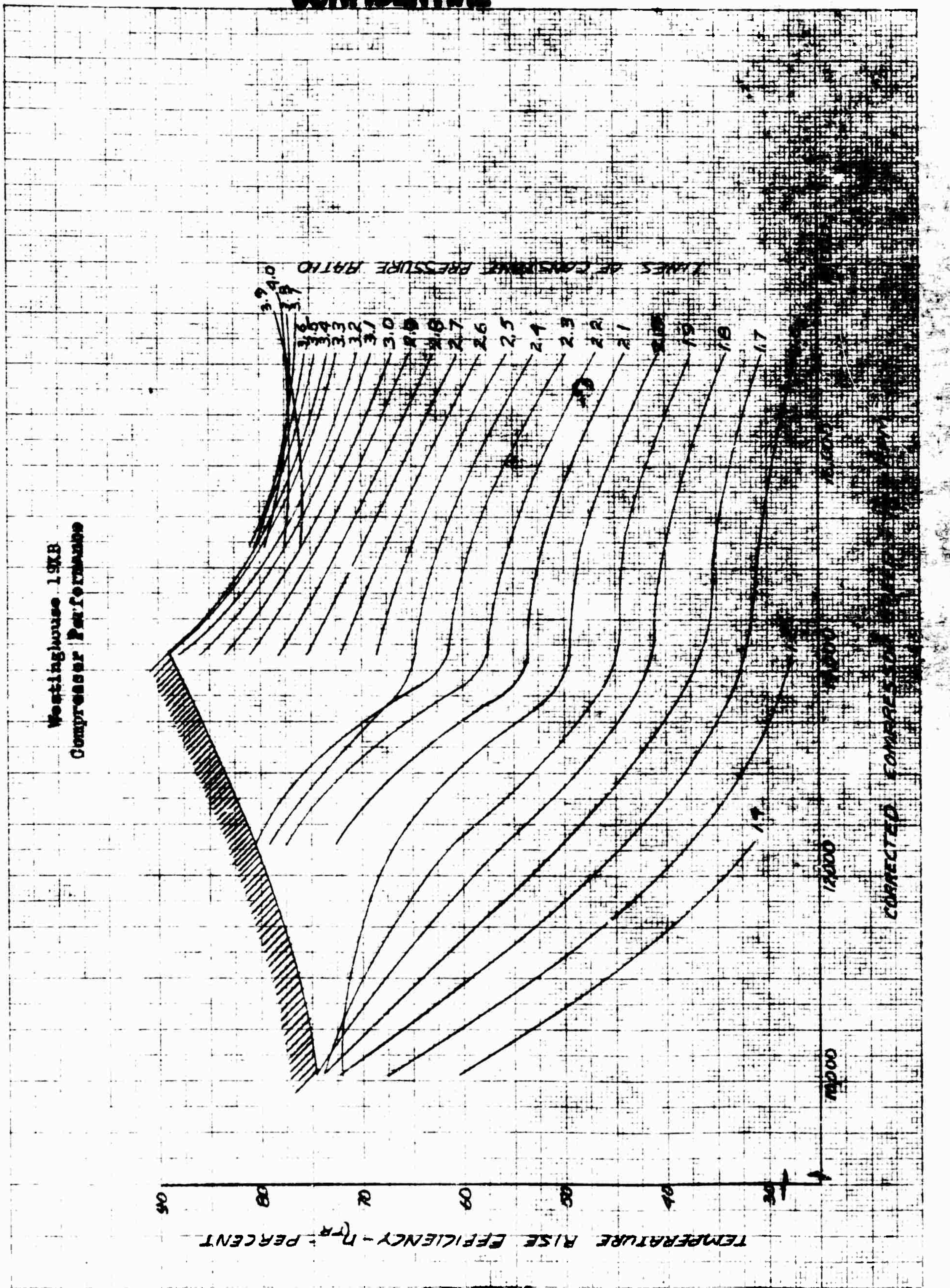

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FIG. 23

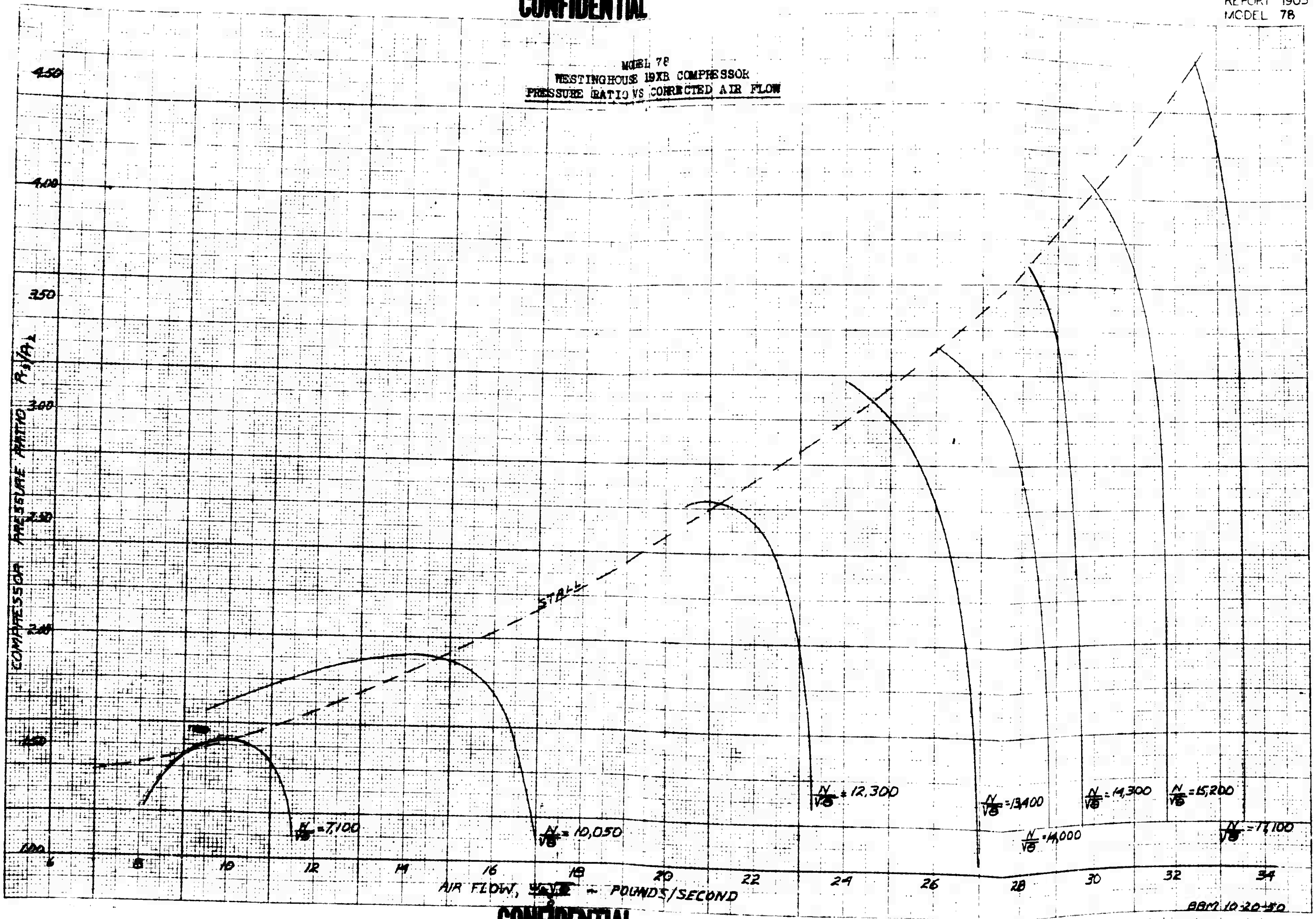
MODEL 78
WESTINGHOUSE 19XB COMPRESSOR
PRESSURE RATIO VS CORRECTED AIR FLOW
STALL
N/√θ = 7,100
N/√θ = 10,050
N/√θ = 12,300
N/√θ = 13,400
N/√θ = 14,000
N/√θ = 14,300
N/√θ = 15,200
N/√θ = 17,100
COMPRESSOR PRESSURE RATIO P_3/P_2
AIR FLOW ~ POUNDS/SECOND
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
BBM 10-20-50

FIG 24

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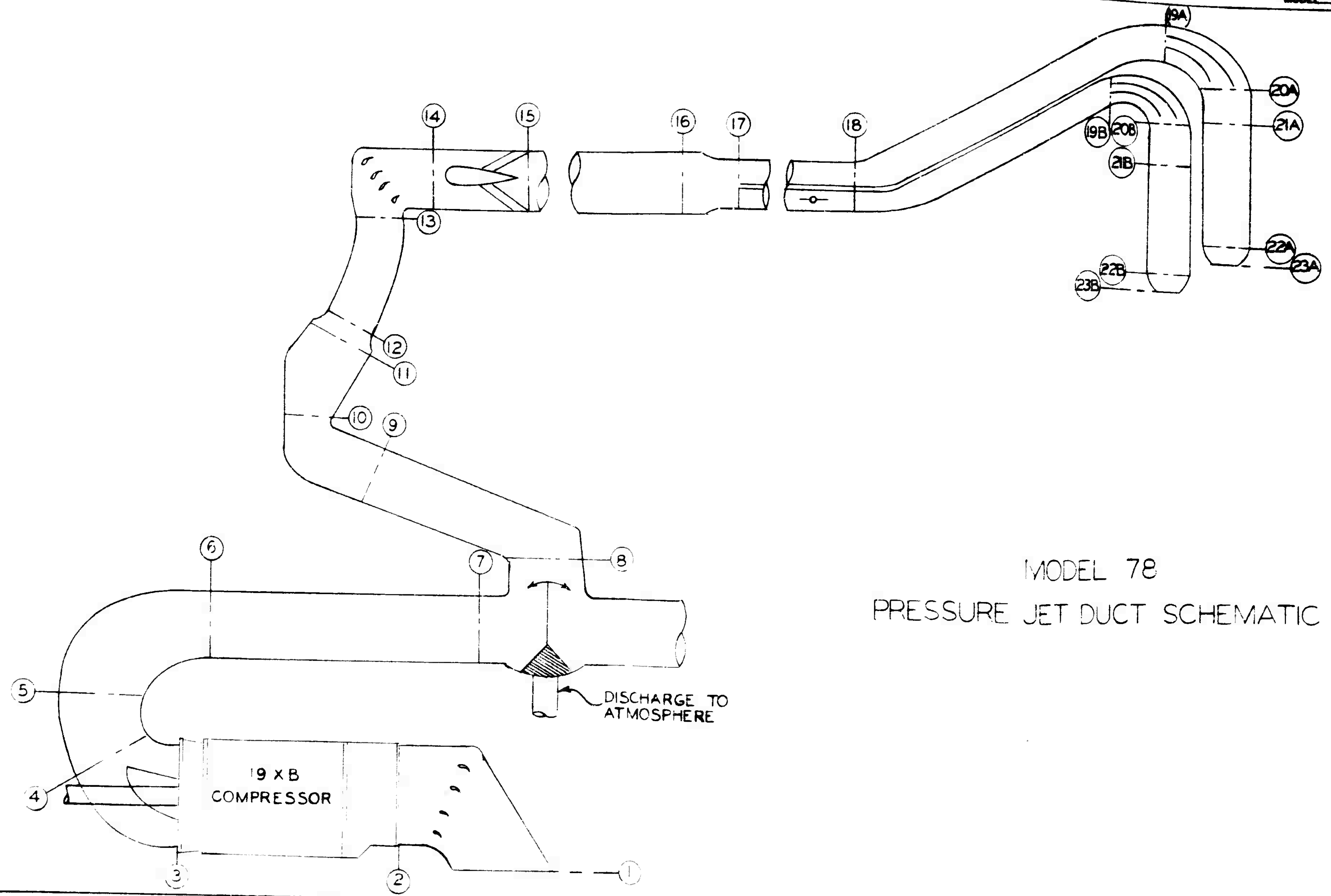

MODEL 78
PRESSURE JET DUCT SCHEMATIC

FIG.25

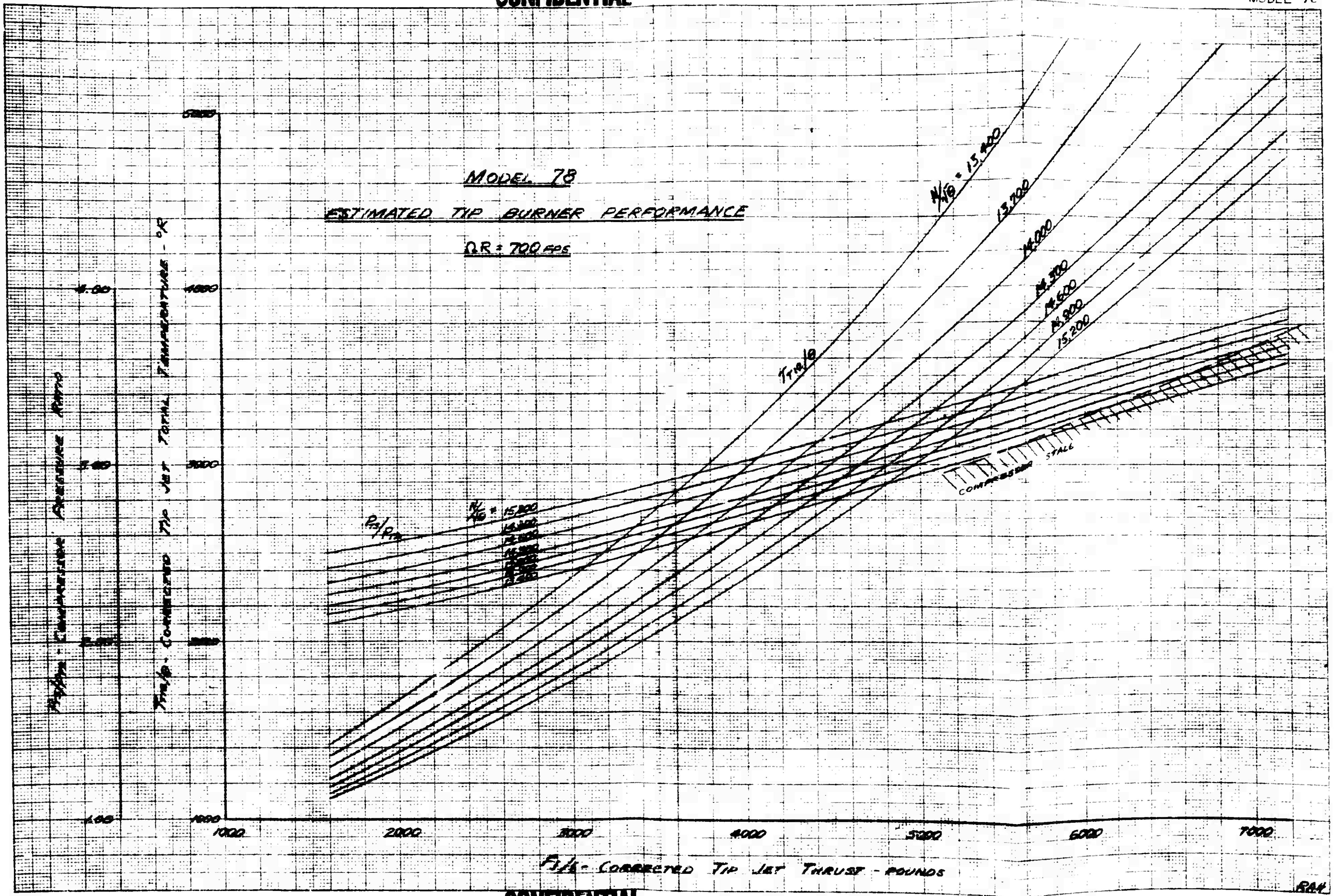
MODEL 78
ESTIMATED TIP BURNER PERFORMANCE
ΩR = 700 FPS
N/√θ = 15,400
13,700
14,000
14,300
14,600
14,900
15,200
T_{TB}/θ
P_{T3}/P_{T2}
COMPRESSOR STALL
P_{T3}/P_{T2} - COMPRESSOR PRESSURE RATIO
T_{TB}/θ - CORRECTED TIP JET TOTAL TEMPERATURE - °R
F_T/δ - CORRECTED TIP JET THRUST - POUNDS
1000
2000
3000
4000
5000
6000
7000
RAH

FIG 26

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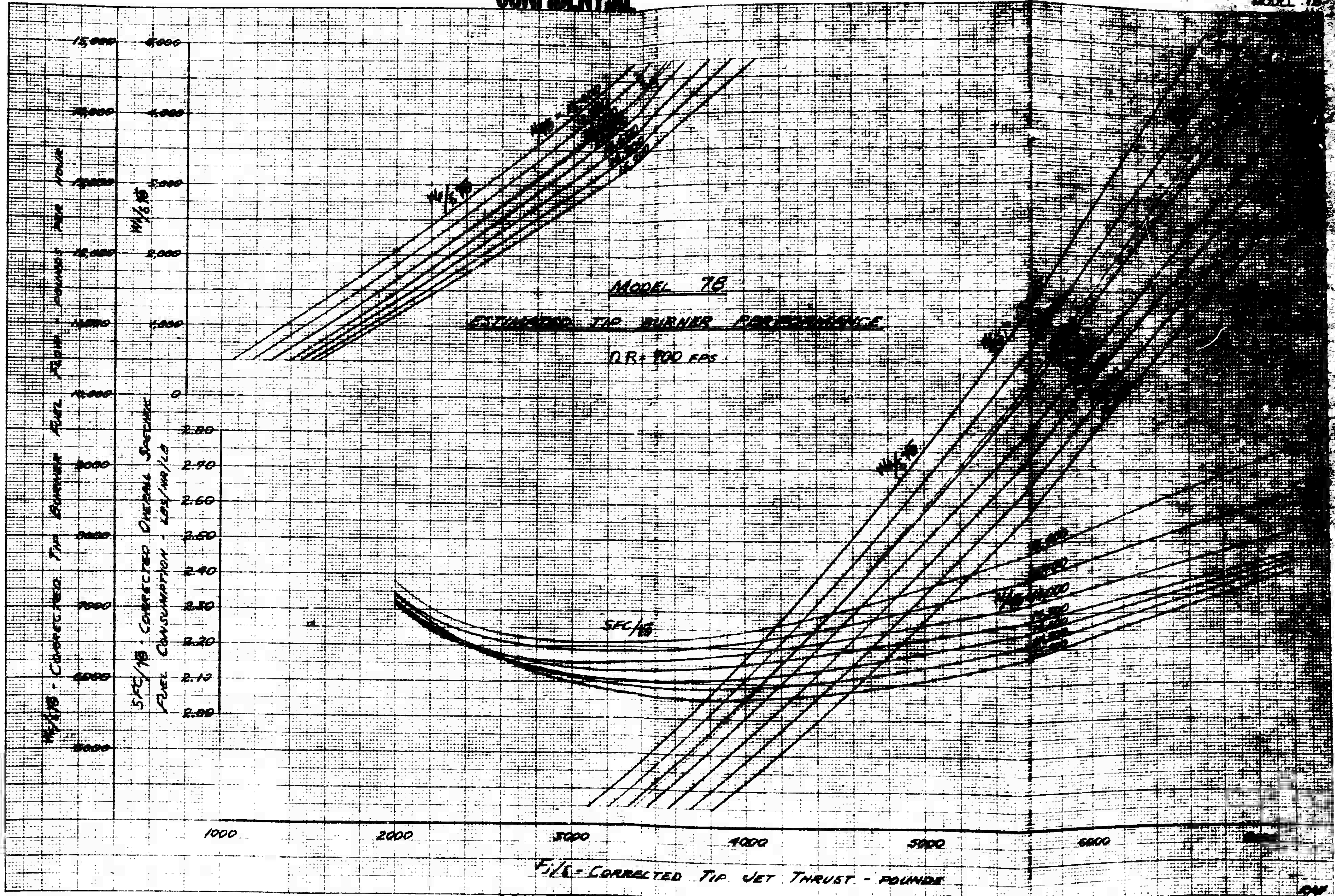

FIG. 27

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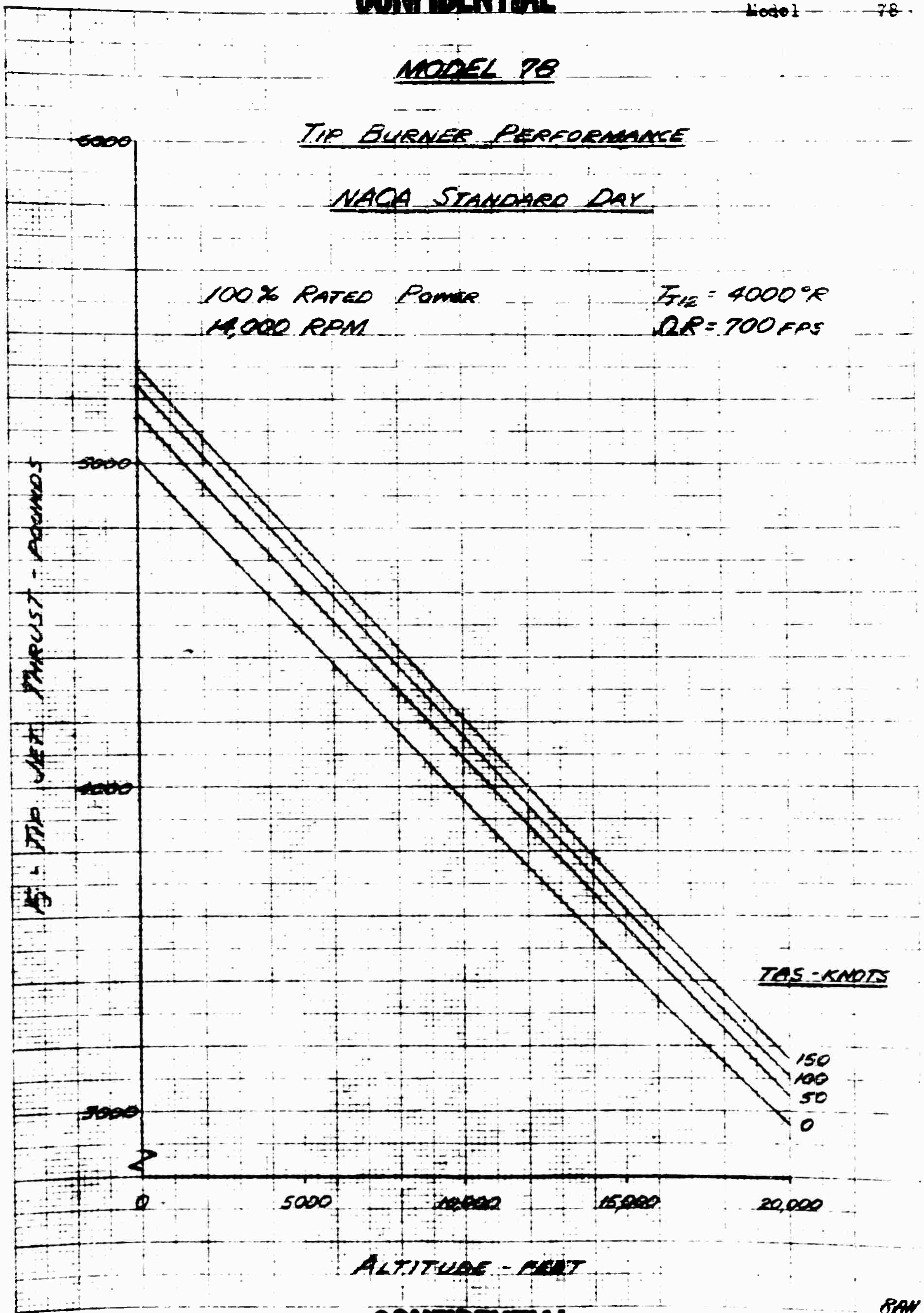
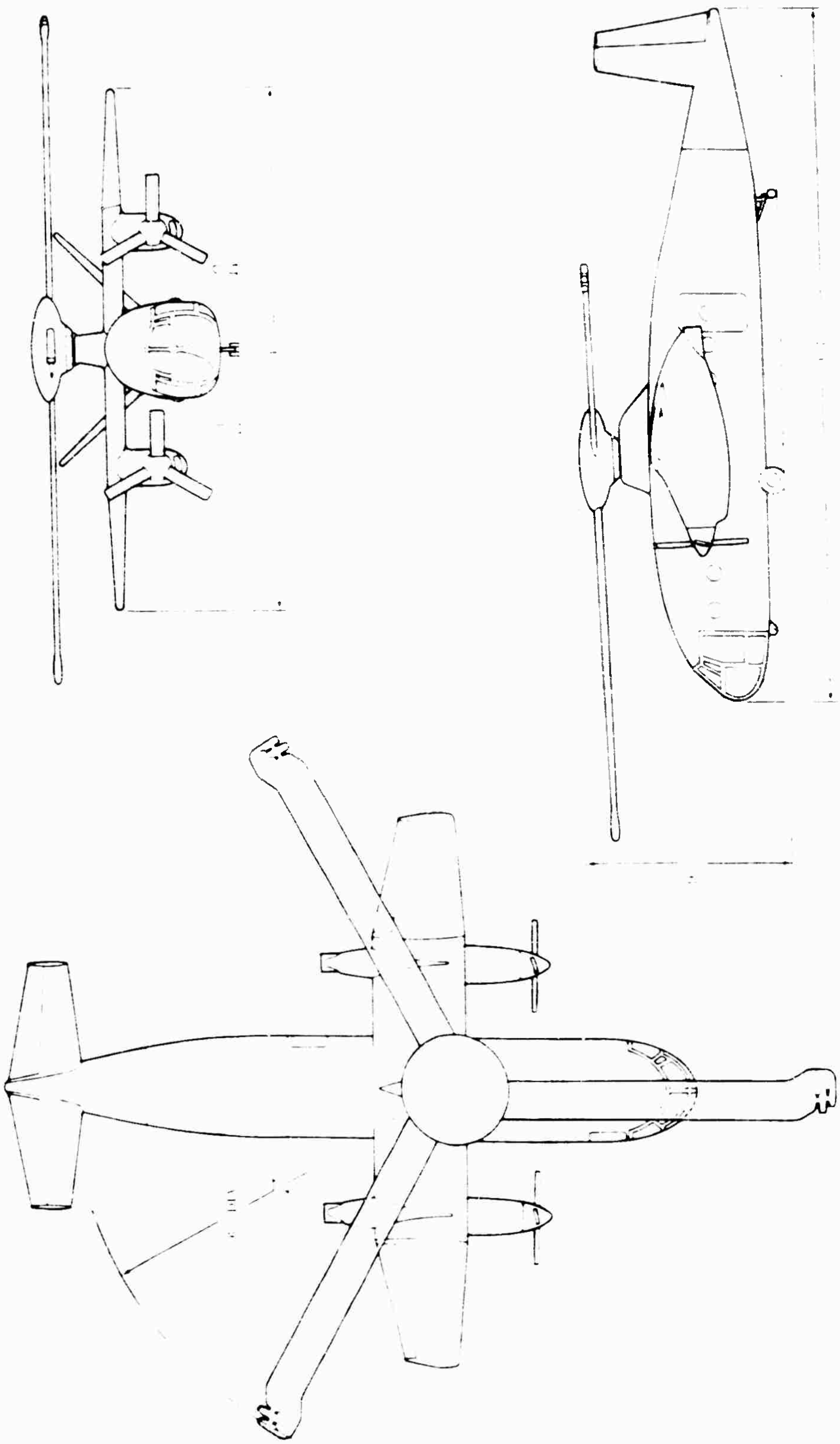
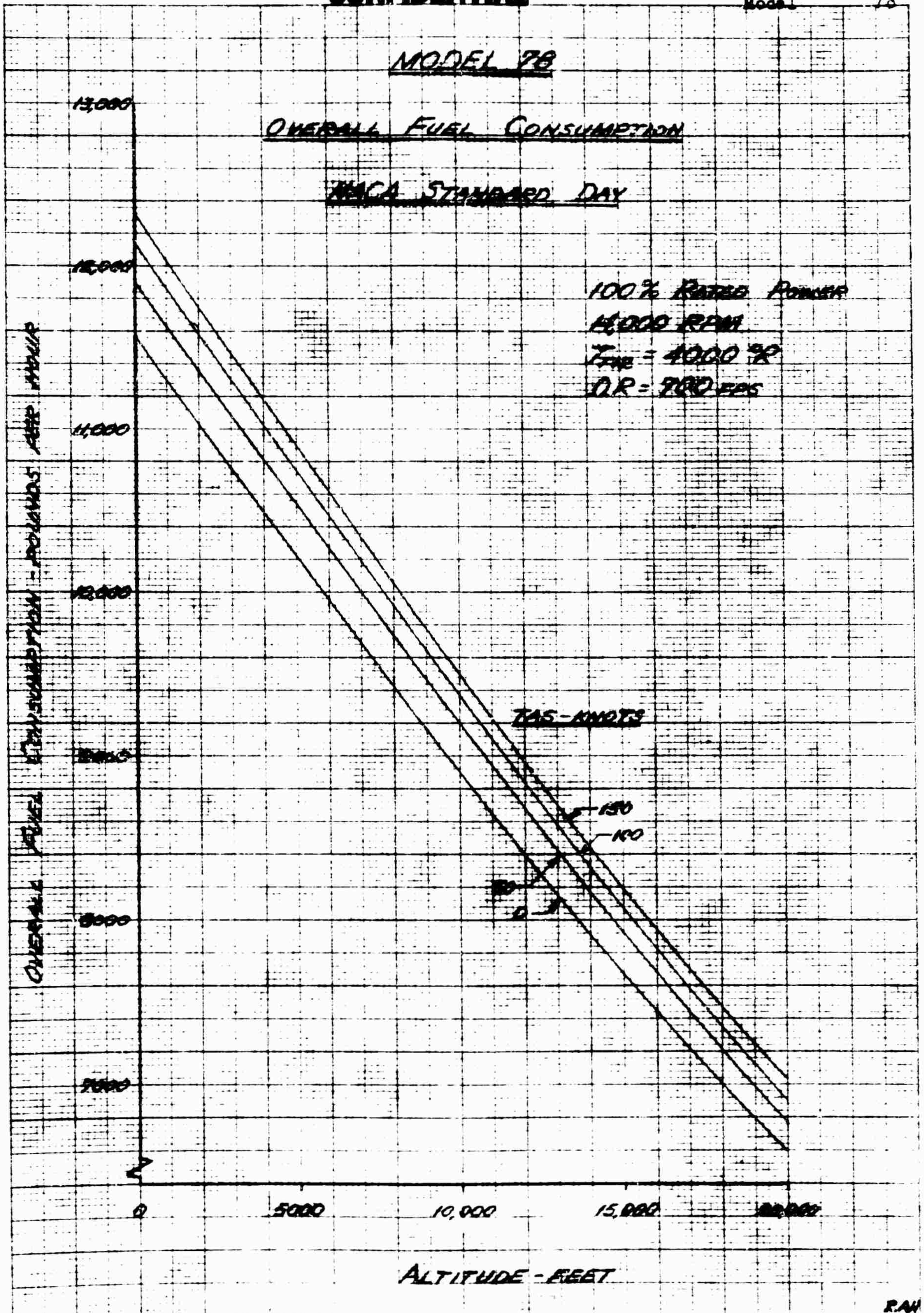

MODEL 78
TIP BURNER PERFORMANCE
NACA STANDARD DAY
100% RATED POWER
14,000 RPM
T_{T12} = 4000°R
ΩR = 700 FPS
6000
5000
4000
3000
TIP JET THRUST - POUNDS
0
5000
10,000
15,000
20,000
ALTITUDE - FEET
TAS - KNOTS
150
100
50
0

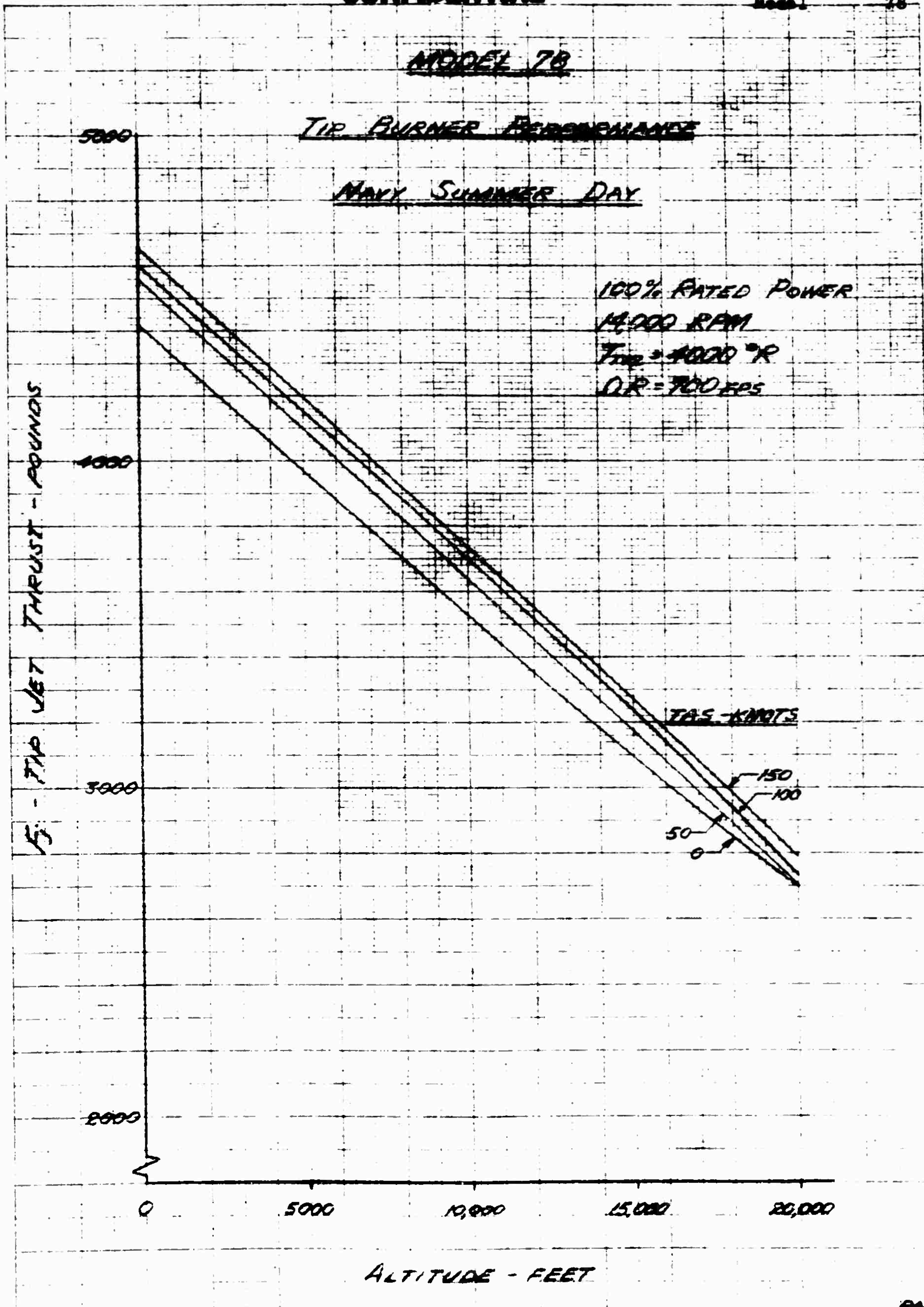
RAW

FIG. 28



MODEL 78 GENERAL ARRANGEMENT


MODEL 78
OVERALL FUEL CONSUMPTION
NACA STANDARD DAY
100% RATED POWER
11,000 RPM
T = 4000 °R
D.R. = 200 FPS
TAS-KNOTS
150
100
50
0
13,000
12,000
11,000
10,000
9000
8000
7000
OVERALL FUEL CONSUMPTION - POUNDS PER HOUR
0
5000
10,000
15,000
20,000
ALTITUDE - FEET
RAH


MODEL 78
TIP BURNER PERFORMANCE
NAVY SUMMER DAY
100% RATED POWER
14,000 RPM
T = 4020 °R
D.R. = 700 PPS
TAS - KNOTS
150
100
50
0
F_j - TIP JET THRUST - POUNDS
5000
4000
3000
2000
0
5000
10,000
15,000
20,000
ALTITUDE - FEET

RAW
FIG. 20

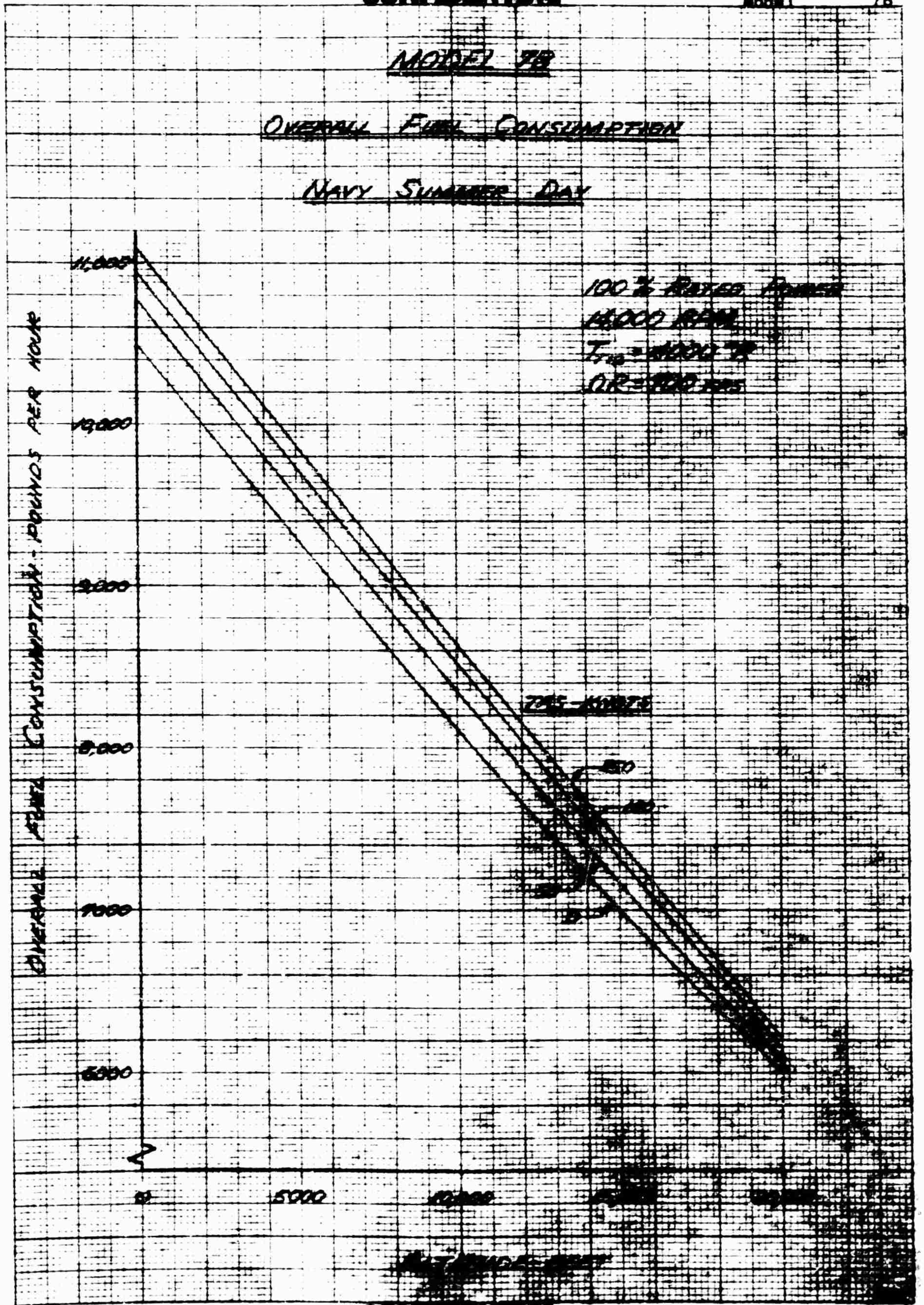

MODEL 78
OVERALL FUEL CONSUMPTION
NAVY SUMMER DAY
100% RATED POWER
14,000 RPM
OVERALL FUEL CONSUMPTION - POUNDS PER HOUR
11,000
10,000
9,000
8,000
7000
6000
0
5000
10,000

FIG. 31

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[illegible]

[illegible] MODEL [illegible] SECTION INLET DUCT ANALYSIS

[illegible] Standard Day, Normal Power

STATION

Quantity		0	1	1.1	1.30	1.4	1.[illegible]0	2
Total temperature, R	T_T	•	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Static pressure, lb./sq. ft. abs.	P	[illegible]	[illegible]	[illegible]	[illegible]	1302	[illegible]	1780
Density, slug/cu. ft.	ρ	[illegible]	[illegible]	.00219	.0021[illegible]	.0021[illegible]	.00217	.00207
Mass flow of air, slug/sec	m	[illegible]	[illegible]	[illegible]	.91[illegible]	.91[illegible]	.91[illegible]	.91[illegible]
Volume flow of air, cu. ft./sec.	Q		[illegible]	417	422	419	42[illegible]	442
Cross sectional area sq. ft.	A		1.11	1.11	1.11	1.23	1.23	1.11
Velocity, ft./sec.	V		3[illegible]	37[illegible]	38[illegible]	3[illegible]	327	396
$\frac{1}{2}\rho V^2$ lb./sq. ft.	q		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	134
Velocity of sound, ft./sec.	a	1120	1110	1110	1110	111[illegible]	1112	110[illegible]
Mach number	M		[illegible]	.338	.343	.29[illegible]	.294	.3[illegible]
Compressibility factor	F_c		1.02[illegible]	1.03	1.031	1.02[illegible]	1.022	1.034
Impact pressure, lb./sq. ft.	q_c		1[illegible]	1[illegible]9	162	118	119	170
Total pressure, lb./sq. ft.	H	[illegible]	2116	204[illegible]	2028	2020	2014	19[illegible]0
Change in total pressure, lb./sq. ft.	ΔH			-72	-1[illegible]	-8.1	-6	-6[illegible]
Change in static pressure, lb./sq. ft.	ΔP			-[illegible]	-10	33	-7	-11[illegible]
Change in total temperature, R	ΔT_T			[illegible]	0	0	0	0
Pressure-loss coefficient	$\Delta H/q_c$			[illegible]	.1	.0[illegible]	.0[illegible]	.[illegible]8
Velocity parameter	[illegible]		[illegible]	.[illegible]1	.396	.302	.304	.724
Static temperature, °R	T	[illegible]1.[illegible]	[illegible]08	[illegible]07	[illegible]07	[illegible]10	10	[illegible]06
Air flow rate, lb./sec.	W_a	29.[illegible]	29.4	[illegible]	29.4	29.4	29.4	[illegible]
Velocity, ft./sec	V		3[illegible]	37[illegible]	377	3[illegible]2	3[illegible]	3[illegible]
Temperature ratio	T_T/T		1.0[illegible]	1.021	1.021	1.01[illegible]	1.01[illegible]	1.024
Pressure ratio P_T/P	P_T/P		1.0[illegible]3	1.07[illegible]	1.07[illegible]	1.0[illegible]7	1.0[illegible]	1.087

TABLE [illegible]

ALLISON MODEL [illegible] [illegible] SECTION INLET DUCT ANALYSIS

Conditions: $V_{[illegible]}$ = 8[illegible] Knots, Sea [illegible], NACA Standard Day, Normal Power

Quantity	Symbol	STATION 0	1	1.1	1.30	1.45	1.60	2
Total temperature, R	T_T	[illegible]20.2	[illegible]20.2	[illegible]0.2	[illegible]20.2	[illegible]20.2	[illegible]	[illegible]20.2
Static pressure, lb./sq. ft. [illegible]	[illegible]	211[illegible]	198[illegible].[illegible]	1901	1883	191[illegible]	1913	1844
Density, slugs/cu. ft.	ρ	.002[illegible]	.0[illegible]	.00219	.00218	.00219	.00219	.0021[illegible]
Mass flow of air, slugs/sec.	m	.[illegible]	.[illegible]	.919	.919	.919	.919	.919
Volume flow of air, cu. ft./sec.	[illegible]		[illegible]09	[illegible]19	42[illegible]	420	420	433
Cross sectional area, sq. ft.	A		1.11	1.11	1.11	1.29	1.29	1.11
Velocity, ft./sec.	V	[illegible].7	369	[illegible]78	383	32[illegible]	3[illegible]	[illegible]90
$\frac{1}{2}\rho V^2$, lb./sq. ft.	q	2[illegible]	1[illegible]	1[illegible]	158	116	11[illegible]	161
Velocity of sound, ft./sec.	a	1120	111[illegible]	[illegible]110	1108	1112	1112	1108
Mach number	M	.131	.33[illegible]	.340	.34[illegible]	.292	.292	.[illegible]2
Compressibility factor	F	1.00[illegible]	1.02[illegible]	1.[illegible]3	1.031	1.022	1.022	1.032
Impact pressure, lb./sq. ft.	[illegible]		1[illegible]8	[illegible]1	1[illegible]3	119	119	16[illegible]
Total pressure, lb./sq. ft.	H	21[illegible].4	21[illegible].4	[illegible]052	2046	2038	20[illegible]2	2010
Change in total pressure, lb./sq. ft.	ΔH		0	-[illegible]	-16	-8	-6	-22
Change in static pressure, lb./sq. ft.	ΔP		[illegible].4	-8[illegible]	-18	3[illegible]	-6	-69
Change in total temperature, R	ΔT_T		0	[illegible]	0	0	0	0
Pressure-loss [illegible]	$\Delta H/q_c$			.	.1	.0[illegible]	.0[illegible]	.18[illegible]
Velocity parameter	[illegible]		.[illegible]	[illegible]68	[illegible]93	[illegible]01	[illegible]02	[illegible]708
Static temperature, °R	T	[illegible].4	[illegible]09.	[illegible]09	[illegible]	[illegible]12	[illegible]11	[illegible]08
Air flow rate, lbs./sec.	Wa	29.	29.	[illegible]	29.[illegible]	29.[illegible]	29.[illegible]	29.[illegible]
Velocity, ft./sec.	V		3[illegible]	[illegible]7[illegible]	[illegible]8	320	32[illegible]	[illegible]8[illegible]
Temperature ratio	T_T/T		1.02	[illegible].022	1.024	1.016	1.017	1.024
Pressure ratio	[illegible]		1.0[illegible]2	1.0[illegible]9	1.037	1.0[illegible]7	1.0[illegible]	1.086

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TABLE 8
ALLISON MODEL [illegible] [illegible] SECTION INLET DUCT ANALYSIS

Conditions: V = 24[illegible] Knots, Sea Level, NACA Standard Day, Normal Power

Quantity	Symbol	STATION 0	1	1.15	1.30	1.45	1.60	2
Total temperature, °R	T_T	[illegible]1.8	[illegible]1.8	[illegible]1.8	[illegible]1.8	531.8	531.8	531.8
Static pressure, lb./sq. ft. abs.	P	211[illegible]	2140	20[illegible]9	204[illegible]	2079	2072	1868
Density, slug/cu. ft.	ρ	.002378	.00241	.0022[illegible]2	.00229	.00233	.00231	.00211
Mass flow of air, slug/sec.	m	.9[illegible]	.9[illegible]	.9[illegible]	.979	.979	.979	.979
Volume flow of air, cu. ft./sec.			40[illegible]	4[illegible]	428	420	424	464
Cross sectional area, sq. ft.	A		1.11	1.11	1.11	1.29	1.29	1.11
Velocity, ft./sec.	V	40[illegible]	36[illegible]	380	385	326	329	418
$\frac{1}{2}\rho V^2$ lb./sq. ft.	q	194	1[illegible]2	1[illegible]	170	124	125	185
Velocity of sound, ft./sec.	a	1120	112[illegible]	112[illegible]	1120	1126	1126	1120
Mach number	M		.32[illegible]	.33[illegible]	.344	.289	.293	.374
Compressibility factor	F_c		1.02[illegible]	1.029	1.031	1.021	1.022	1.036
Impact pressure, lb./sq. ft.	qF_c		1[illegible]	173	173	127	128	192
Total pressure, lb./sq. ft.	H	231[illegible]	231[illegible]	2252	2215	2206	2200	2060
Change in total pressure, lb./sq. ft.	ΔH	0		-65	-17	-88	-64	-140
Change in static pressure, lb./sq. ft.	ΔP	33		-90	-19	39	-7	-[illegible]4
Change in total temperature °R	ΔT_T	0		[illegible]	0	0	0	0
Pressure-loss coefficient	$\Delta H/q_c$			.3	.1	.05	.05	1.09
Velocity parameter	$RWa/r_T A$		.654	.678	.663	.590	.598	.736
Static temperature, °R	T	518.4	520.5	52[illegible]	[illegible]19.6	52[illegible].1	522.6	517.8
Air flow rate, lb./sec.	Wa	31.[illegible]	31.[illegible]	31.[illegible]	31.[illegible]	31.5	31.[illegible]	31.5
Velocity, ft./sec.	V		370	[illegible]	385	325	328	415
Temperature ratio	T_T/T	1.02	1.02[illegible]	1.0[illegible]	1.023	1.016	1.017	1.026
Pressure ratio	H/P	1.094	1.07[illegible]	1.0[illegible]	1.063	1.0[illegible]7	1.061	1.094

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TABLE 4

SUMMARY OF ALLISON MODEL 501 POWER SECTION INLET DUCT ANALYSIS

Sea Level, Normal Power

Condition	Static	V_o = 87 Knots	V_o = 240 Knots
Velocity ratio V_i/V_o	$\sim$	2.01	0.903
Angle of Attack α	2.0	0	0
Estimated H/q_i	1.11	0.815	1.54

Estimate of losses through the duct

Static

Condition: Section	0-1	1-1.15	1.15-1.3	1.3-1.45	1.45-1.6	1.6-2
$\Delta H/q_{local}$		.4800	.1040	.0516	.0522	.3820
q_{local}/q_c	∞	.9150	.9390	.9570	.7010	.7070
$\Delta H/q_c$		.4390	.0976	.0494	.0366	.3900
Total H_{ot}/q_c				1.0126		

V_o = 87 Knots

Section	0-1	1-1.15	1.15-1.3	1.3-1.45	1.45-1.6	1.6-2
$\Delta H/q_{local}$		.516	.1025	.0506	.0518	.190
q_{local}/q_c	.159	.93	.968	.982	.721	.721
$\Delta H/q_c$		.4920	.0994	.0497	.0373	.1370
Total H_{ot}/q_c				.8131		

V_o = 240 Knots

Section	0-1	1-1.15	1.15-1.3	1.3-1.45	1.45-1.6	1.6-2
$\Delta H/q_{local}$		.513	.010	.0518	.0517	1.12
q_{local}/q_c	1.05	.876	.909	.919	.671	.675
$\Delta H/q_c$		.448	.0919	.0476	.0346	.757
Total H_{ot}/q_c				1.3791		

Over-all pressure loss and effect upon engine performance

Condition	Static	V_o = 87 Knots	V_o = 240 Knots
$\Delta H_{ot}/q_c$	1.0126	.8131	1.3791
$\Delta H_{ot}/H_{ot}$	.0784	.0611	.11
$\Delta SHP/SHP$	.126	.0662	.0602
$\Delta F/F$	.122	.0791	.0769
$\Delta W_F/W_F$	.0644	.0337	.0272

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TABLE 5

WESTINGHOUSE 19XB [illegible]

Condition: Static, Sea Level, NACA Standard [illegible]

	Quantity	Symbol	0	1	1.1	2
1	Total temperature, °F	T_T	518.4	[illegible]	[illegible]	518.4
2	Static pressure, lbs./sq.ft. abs.	P	211[illegible]	[illegible]	[illegible]	1792
3	Density, slug/cu.ft.	ρ	.00[illegible]	[illegible]	[illegible]	.00207
4	Mass flow of air, slug/sec.	m	.714	[illegible]	[illegible]	.714
5	Volume flow of air, cu.ft./sec.	Q		330	300	3[illegible]
6	Cross-sectional area, sq.ft.	A	.[illegible]	.[illegible]	[illegible]	.935
7	Velocity, ft. sec.	V		[illegible]	[illegible]	385
8	$\frac{1}{2}\rho V^2$, lbs./sq.ft.	q		1[illegible]	14[illegible]	1[illegible]
9	Velocity of sound, ft. sec.	[illegible]	112[illegible]	111[illegible]	111[illegible]	11[illegible]
10	Mach number	M		.31[illegible]	[illegible]	[illegible]
11	Compressibility factor	F_c		1.[illegible]	1.[illegible]	1.[illegible]1
12	Impact pressure, lbs./sq.ft.	qF_c		1[illegible]	1[illegible]	[illegible]
13	Total pressure, lbs./sq.ft.	[illegible]	2116	[illegible]	2[illegible]	1[illegible]
14	Change in total pressure, lbs./sq.ft.	ΔH			-[illegible]	-[illegible]
15	Change in static pressure, lbs./sq.ft.	ΔP			-[illegible]	-[illegible]
16	Change in total temperature, °F	ΔT_T			[illegible]	[illegible]
17	Pressure-loss coefficient	$\Delta H/q$			[illegible]	[illegible]
18	Velocity parameter	[illegible]	.647	.[illegible]	[illegible]	.[illegible]
19	Static temperature, °F	T	51[illegible].4	[illegible]	[illegible]	[illegible]
20	Airflow rate, lbs./sec.	[illegible]	24.	2[illegible]	[illegible]	[illegible]
21	Velocity, ft. sec.	[illegible]		[illegible]	3[illegible]	[illegible]
22	Temperature ratio	[illegible]		1.[illegible]	1.[illegible]	1.[illegible]
23	Pressure ratio	[illegible]		1.[illegible]	[illegible]	1.[illegible]

TABLE 7 - ANALYSIS OF PRESSURE JET SYSTEM

$N/\sqrt{\theta} = 14{,}000$ $P_{T_3}/P_{T_2} = 2.40$

Station		0	3	4	5	6	7	8
Qty.	Unit							
Wa	#/sec		28.45	28.45	28.45	28.45	28.45	56.90
T_T	°R	518.4	740	740	740	740	740	740
P_T	PSIA	14.7	35.28	35.18	34.96	34.77	34.59	34.37
A	in^2		187	100	100	100	100	200
RW_a/P_TA			.230	.431	.434	.436	.438	.441
V	ft/sec		170	328	331	333	334	337
T	°R		737.62	731.13	730.97	730.86	730.81	730.75
γ			1.3942	1.3944	1.3944	1.3944	1.3944	1.3945
$\gamma/\gamma-1$			3.5368	3.5355	3.5355	3.5355	3.5355	3.5349
T_T/T			1.00323	1.01213	1.01235	1.01251	1.01258	1.01266
P_T/P			1.01147	1.04360	1.04440	1.04487	1.04512	1.04540
P	PSIA		34.88	33.71	33.47	33.28	33.10	32.88
qo	PSI		0.40	1.47	1.49	1.49	1.49	1.49
ρ	ft		2.95*	2.95	2.95	2.95	2.95	4.767
Wa/gp			.300	.300	.300	.300	.300	.371
RN			$2.45x10^6$	$2.45x10^6$	$2.45x10^6$	$2.45x10^6$	$2.45x10^6$	$3.1x10^6$
f					.0031			
1/D					10.15			
$\Delta H/q$			.25	.15	.12[illegible]	.12	.1[illegible]	.05
ΔH			.10	.22	.19	.13	.22	.07
V_{T_x}								
V_{T_y}								
$V_{T_y}-V_{T_x}$								
P_{T_y}/P_{T_x}								
ΔH								

TABLE 7 Continued

Qty.	Station Unit	9	10	11	12	13	14	15
W_a	#/sec	56.90	56.90	56.90	56.90	18.97	18.97	18.97
T_T	°R	740	740	740	740	740	740	740
P_T	PSIA	34.30	34.15	33.87	33.83	33.80	33.53	33.23
A	in^2	200	209	410	251	78.4	44.2	44.2
RW_a/P_TA		.442	.425	.218	.357	.382	.682	.688
V	ft/sec	338	323	162	268	288	551	557
T	°R	730.58	731.40	737.84	734.08	733.17	715.96	714.41
γ		1.3945	1.3944	1.3941	1.3943	1.3944	1.3950	1.3950
$\gamma/\gamma -1$		3.5349	3.5355	3.5374	3.5361	3.5355	3.5316	3.5316
T_T/T		1.01289	1.01176	1.00293	1.00806	1.00932	1.03358	1.03582
P_T/P		1.04632	1.04215	1.01040	1.02876	1.03334	1.1238	1.1323
P	PSIA	32.78	32.77	33.52	32.88	32.71	29.84	29.35
qc	PSI	1.52	1.38	0.35	0.95	1.09	3.69	3.88
ρ	ft	4.767			14.45			1.96
W_a/gp		.371			.122			.300
RN		$3.1x10^6$			$1.1x10^6$			$2.45x10^6$
f					.0035			.0031
1/D					1.90			11.3
$\Delta H/q$		.10	.20	.10	.027	.25	.10	.14
ΔH		.15	.28	.04	.03	.27	.37	.64
V_{T_x}							0	75
V_{T_y}							75	220
$V_{T_y} - V_{T_x}$							5625	42,775
P_{T_y}/P_{T_x}							1.00223	1.01698
ΔH								.07

TABLE 7 Continued

Station Qty.	Units	16	17a	18a	19a	20a	21a	22a
Wa	#/sec	18.97	9.48	9.48	9.49	9.48	9.48	
T_T	°R	740	740	740	740	740		
P_T	PSIA	33.25	33.25	36.01	36.85	36.84	35.54	35.22
A	in^2	44.2	24.3	24.3	24.3	48.4		
RWa/P_TA		.688	.625	.577	.564	.284		
V	ft/sec	557	498	453	441	212		
T	°R	714.41	719.55	723.08	723.97	736.30		
γ		1.3950	1.3948	1.3947	1.3947	1.3943		
$\gamma/\gamma -1$		3.5316	3.5329	3.5336	3.5336	3.5361		
T_T/T		1.03582	1.02842	1.02340	1.02214	1.00503		
P_T/P		1.1323	1.1040	1.0850	1.08035	1.01790		
P	PSIA	29.37	30.12	33.19	34.11	36.19		
qc	PSI	3.88	3.13	2.82	2.74	.65		
ρ	ft		17.08					
Wa/qp			.172					
RN			1.45x10^6					
f			.0033					
1/D			44.0					
ΔH/q		.001	.58	.15	.15	2.0		
ΔH		0	1.82	.42	.41	1.30	.32	
V_{T_x}			220	618	680			
V_{T_y}			618	680	700			
$V_{T_y} - V_{T_x}$			333,524	80,476	27,600			
P_{T_y}/P_{T_x}			1.1378	1.0350	1.01089			
ΔH	.56	0	4.58	1.26	.40			

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TABLE 7 Continued

Station		23a	17b	18b	19b
Qty.	Units				
Wa	#/sec		9.48	9.48	9.48
T_T	°R	1885	740	740	740
P_T	PSIA	35.22	33.25	35.89	36.62
A	in^2	22.51	22.1	22.1	22.1
RWa/P_TA			.688	.637	.624
V	ft/sec	1932	557	507	.497
T	°R	1594	714.41	718.80	719.63
γ			1.3950	1.3949	1.3948
$\gamma/\gamma-1$			3.5316	3.5323	3.5329
T_T/T			1.03582	1.02949	1.02831
P_T/P			1.1323	1.1060	1.1034
P	PSIA		29.37	32.39	33.19
qc	PSI		3.88	3.50	3.43
ρ	ft		1.39		
Wa/gp			2.11		
RN			1.65×10^6		
f			.0032		
l/D			39.34		
$\Delta H/q$			.50	.15	.15
ΔH			1.94	.53	.51
V_{T_x}					
V_{T_y}					
$V_{T_y} - V_{T_x}$					
P_{T_y}/P_{T_x}			1.1378	1.0350	1.01089
ΔH			4.08	1.26	.40

TABLE 7 Continued

Station		20b	21b	22b	23b
Qty.	Unit				
Wa	#/sec	9.48	9.48		
T_T	°R	740			1865
P_T	PSIA	36.51	35.21	34.91	34.91
A	in^2	48.4			22.51
RW_a/P_TA		.283			
V	ft/sec	213			1922
T	°R	730.26			1576
γ		1.3943			
$\gamma/\gamma-1$		3.5361			
T_T/T		1.00508			
P_T/P		1.01808			
P	PSIA	35.86			
qo	PSI	.65			
ρ	ft				
Wa/q_F					
RN					
1/D					
$\Delta H/q$			2.0		
ΔH			1.30	.30	
V_{T_x}					
V_{T_y}					
$V_{T_y}-V_{T_x}$					
P_{T_y}/P_{T_x}					
ΔH					

TABLE 7 Continued

Duct Qty.	Unit	a	b	Total Model 78
A	ft^2	.1563	.15[illegible]3	469
P_{T22}	PSIA	35.22	34.[illegible]1	
γ		1.3649	1.3664	
$\gamma/\gamma-1$		3.74[illegible]5	3.[illegible]293	
$(2/\gamma+1)^{\gamma-1}$		.5345	.5[illegible]5	
P_{23}	PSIA	18.83	18.66	
W_g	#/sec	9.6[illegible]	9.[illegible]1	
T_{23}	^oR	1594	1[illegible]6	
T_T	^oR	1885	1865	1875
C_{pav}		.2575	.2571	
ΔT	^oR	858	84[illegible]	
W_F	#/sec	.12931	.12637	.76704
W_F	#/hr	465.5	4[illegible].9	2761
F/A		.01364	.01333	
V	ft/sec	1932	1[illegible]22	
$\eta \frac{W_g}{g} \Delta V$	#	350	346	
$(\Delta P)A$	#	93	89	
F_J	#	443	[illegible]	2634
HP_{req}				4290
$HP_{output/engine}$				2283
W_{F_E}/engine				1480
W_{F_E} total				2960
$W_{F_E}+W_{F_J}$				[illegible]721
Overall SFC				2.17